6-E
ROUTE 9 SITE RUNOFF EFFECTS ON THE GEOMORPHOLOGY OF LITTLE BEAR CREEK

FINAL ENVIRONMENTAL IMPACT STATEMENT

Brightwater Regional Wastewater Treatment System

APPENDICES

Brightwater
TREATMENT SYSTEM

Final

Appendix 6-E
Route 9 Site Runoff Effects on the Geomorphology of Little Bear Creek

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A. Characterization of Hydrology Surrounding Brightwater Regional Wastewater Treatment System – Proposed Route 9 Plant Site in the Little Bear Creek Drainage (Currently being prepared by Aqua Terra)

B. Grain Size Distribution of Sediment Samples Collected from Little Bear Creek

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King County has prepared a Draft Environmental Impact Statement (Draft EIS) and Final Environmental Impact Statement (Final EIS) on the Brightwater Regional Wastewater Treatment System. The Final EIS is intended to provide decision-makers, regulatory agencies, and the public with information regarding the probable significant adverse impacts of the Brightwater proposal and identify alternatives and reasonable mitigation measures.

King County Executive Ron Sims has identified a preferred alternative, which is outlined in the Final EIS. This preferred alternative is for public information only, and is not intended in any way to prejudge the County's final decision, which will be made following the issuance of the Final EIS with accompanying technical appendices, comments on the Draft EIS and responses from King County, and additional supporting information. After issuance of the Final EIS, the King County Executive will select final locations for a treatment plant, marine outfall, and associated conveyances.

The County Executive authorized the preparation of a set of Technical Reports, in support of the Final EIS. These reports represent a substantial volume of additional investigation on the identified Brightwater alternatives, as appropriate, to identify probable significant adverse environmental impacts as required by the State Environmental Policy Act (SEPA). The collection of pertinent information and evaluation of impacts and mitigation measures on the Brightwater proposal is an ongoing process. The Final EIS incorporates this updated information and additional analysis of the probable significant adverse environmental impacts of the Brightwater alternatives, along with identification of reasonable mitigation measures. Additional evaluation will continue as part of meeting federal, state, and local permitting requirements.

Thus, the readers of this Technical Report should take into account the preliminary nature of the data contained herein, as well as the fact that new information relating to Brightwater may become available as the permit process gets underway. It is released at this time as part of King County's commitment to share information with the public as it is being developed.

1.0 INTRODUCTION

The flow in a stream channel plays an important role in determining the physical channel shape, slope, and erosion/sedimentation characteristics. These are major components in the channel-forming process known as channel geomorphology. This technical memorandum has been prepared to review the runoff effects of the proposed project at the Route 9 site on the geomorphic characteristics of Little Bear Creek.

In addition to the Introduction, there are three sections to this memo. Section 2 reviews the hydrology of Little Bear Creek and the small streams that currently flow through the project site. Section 2 also quantifies the proposed diversion of streams around the project site and flow effects of stormwater runoff from the project site. Chapter 3 summarizes findings from a previous study of conditions on Little Bear Creek. It also presents the results of a reconnaissance-level survey of a portion of Little Bear Creek near the project site. Chapter 4 presents an evaluation of the effects of post-project flows on channel stability and stream flooding.

2.0 HYDROLOGIC ANALYSIS

A hydrologic modeling study was carried out by Aqua Terra. The report produced by that study is included with this technical memorandum as Attachment A. The purpose of the modeling study was to provide flow information on the small streams and water courses flowing across the Route 9 site, and their flow contribution to Little Bear Creek. The study also quantified flow effects of the project site runoff on Little Bear Creek. Specific objectives of the study included:

1. Quantifying the hydrology of the streams and watercourses flowing through the project site.
2. Evaluating the effects of proposed stream diversions and detention of project runoff on the hydrology of Little Bear Creek.

2.1 HSPF Model

The Hydrologic Simulation Program – Fortran (HSPF) model used for this analysis is based on the original Little Bear Creek HSPF model developed for King County as part of the Lake Sammamish and Lake Washington Modeling Project. HSPF integrates meteorologic and hydrologic data collected near the subbasin with topography, land use, and stream channel information to provide long-term simulated streamflow hydrographs for existing conditions. The model was modified to evaluate the effects of the project on Little Bear Creek.

The project site is bounded on the east by railroad tracks and on the west by State Route 9 (SR-9). The northern third of the site is second-growth forest and disturbed wetland. The central portion of the site contains recently graded open lots, a warehouse, and a factory. Most of the remainder of the site consists of large auto yards and commercial and light industrial uses.

Numerous small streams and watercourses flow across the project site (Figure 1). Howell Creek runs along the south side of the project site and Unnamed Creek is located at the north side. Between these two streams are (from south to north) Watercourses 3 through 8, Channel B, and Channel A (also known as 228th Street Creek). These streams flow across the project site in a series of pipes and open channels and discharge to the SR-9 drainage system along the west side of the site. Runoff in this drainage system crosses under SR-9 through several culverts and then continues to Little Bear Creek.

For modeling purposes, the project site, and the upslope contributing area north and east of the site, were divided into 35 sub-catchments. This allowed existing flow conditions in the streams and watercourses and their post-project diversions to be analyzed. Model output for Little Bear Creek was obtained for three key reaches (Figure 1):

- Reach 190 – upstream of project influence, near a point where an unnamed stream north of the project site flows into Little Bear Creek
- Reach 220 – The reach of Little Bear Creek between Unnamed Creek and Howell Creek
- Reach 240 – the inflow from Howell Creek, immediately downstream of the project site

The treatment plant will occupy about 65 acres in the central and southern portions of the project site. Pervious and impervious acreages were calculated from a conceptual drawing of the plant layout (Figure 2) and input into the model. Guidelines in Washington State Department of Ecology's Stormwater Management Manual for Western Washington, known as the Ecology Manual (Ecology, 2001) were used to calculate stormwater detention requirements. For convenience, the model routed discharge from a single detention pond to Little Bear Creek midway along the project site (Reach 220).

The watercourses are proposed to be diverted south to Howell Creek. Channels A and B are proposed to be diverted around the north side of the project site. The catchments of all of these streams upstream of the railroad tracks were routed appropriately in the post-project version of the model.

More information on model setup, model schematics, and input can be found in Attachment A.

2.2 Results and Analysis

Flow frequency (peak flow) information was computed for existing and post-project conditions for the 1-, 2-, 5-, 10-, 25-, and 100-year storm events. Mean monthly flows were also computed. Flow duration curves were developed for selected locations. Detailed data can be found in Attachment A.

Table 1 lists the average annual flow, the highest average monthly flow (January), and the lowest average monthly flow (August). The flows for Channels A and B and the watercourses are for locations immediately upstream of the project site. Their mean annual flows are relatively low, ranging from 0.02 to 0.3 cubic feet per second (cfs). This is reflective of their generally small drainage areas. Summer low flows (August) range from 0.01 to 0.11 cfs. Most of the watercourses are dry for a portion of the summer season.

TABLE 1
Streams Upslope of the Project Site
(flows in cfs)

Stream	Average Annual	January	August	Drainage Area (acres)
Channel A	0.13	0.23	0.05	51.9
Channel B	0.12	0.21	0.06	52.3
Watercourses:				
8	0.30	0.55	0.12	137.5
7	0.04	0.06	0.02	17.0
6	0.02	0.03	0.01	6.9
5	0.02	0.03	0.01	7.9
4	0.06	0.10	0.03	26.3
3	0.05	0.09	0.02	26.2
Little Bear Creek [1]	17.8	31.4	7.6	8,143
Howell Creek [2]	0.29	0.51	0.13	133
Unnamed Creek[3]	0.15	0.24	0.08	64.0

[1] At the inflow of Howell Creek (Reach 240)
[2] At SR-9
[3] Upstream of SR-9.

Both Unnamed and Howell Creeks have relatively low flows, averaging about 0.29 and 0.15 cfs, respectively. Little Bear Creek drains the general area (12.7 square miles at the point where Howell Creek joins it) and has considerably higher flows. Mean annual flow is 17.8 cfs. The high and low monthly flows are 31.4 and 7.6 cfs, respectively.

The project will detain stormwater from approximately 64 acres of the project site. Flow from onsite streams and watercourses will be diverted to Howell and Unnamed Creeks. This will result in changes in the hydrology of Unnamed Creek, Howell Creek, and Little Bear Creek. Table 2 shows the peak flows (existing conditions and post-project) for the 2-, 10-, and 100-year flows.

For Little Bear Creek, runoff from the project site will be detained to forested conditions. Detained runoff from the project site is calculated to be about 2.2 cfs for the 100-year storm. This value will be refined as the project moves into the design phase, but is not expected to change substantially.

TABLE 2
Project Effect Upon Peak Flows In Little Bear Creek
(Return Interval-Years)

Existing (cfs)	**2**	**10**	**100**
Upstream	261	416	653
Adjacent	329	513	790
Downstream	392	600	894
Post Project (cfs)			
Upstream	261	416	653
Adjacent	328	512	786
Downstream	379	580	863
% Increase			
Upstream	0	0	0
Adjacent	0	0	0
Downstream	-3.3%	-3.3%	-3.5%
Detained Runoff from the Project Site (cfs)	0.9	1.4	2.2

There would be no flow changes in Little Bear Creek upstream of the confluence with Unnamed Creek because the upstream area would not be affected by the proposed Brightwater treatment plant. The Little Bear Creek reach immediately adjacent to the Brightwater treatment plant would also be minimally affected. For modeling purposes, all project stormwater discharges were assumed to be routed to the adjacent reach of Little Bear Creek. This is a conservative assumption because some of the stormwater discharge will be routed to Little Bear Creek downstream of this location. Downstream of the project site, modeled peak flows in Little Bear Creek show a 3 percent decrease (31 cfs decrease for the 100-year flow). Most of this is attributable to stormwater detention achieved at the project site.

Tables 3 and 4 show the effects of the proposed flow diversions on Howell and Unnamed Creeks. As stated, the watercourses would be routed south to join with Howell Creek. Unnamed Creek is proposed to be routed through the wetlands on the northern end of the Route 9 site, east of SR-9, where it would receive the inflows from Channels A and B. It would then flow through the existing 73-inch by 55-inch arch culvert (located immediately downstream of the Fish Pond) under SR-9 to Little Bear Creek. Both creeks show major increases in peak flows resulting from the streams or watercourses directed to them. Peak flows in Unnamed Creek would increase by about fourfold. Peak flows in Howell Creek would increase by 50 to 100 percent. Both of these streams are currently channelized in their reaches above SR-9. The channels of both streams are proposed to be rerouted and enhanced. As part of this enhancement, hydraulic analysis will be carried out on the channels of these streams. The channels would be designed and stabilized to handle the increased, post-project flows. The existing Howell Creek culvert under SR-9 is undersized to handle the post-project flows and will need to be upgraded.

TABLE 3
Peak Flows In Unnamed Creek Following Flow Diversions [1]

	Return Interval-Years			
	2	**10**	**100**	**Drainage Area (acres)**
Existing (cfs)	4.1	6.5	9.5	64
Post-Project (cfs)	19.7	32.3	48.2	203
% Increase	380%	397%	407%	217%

[1] At SR-9

The post-project, mean annual and mean monthly flows in Little Bear Creek would decrease slightly. This would result from the net increase of approximately 37 acres of previous area of the project site and its associated evapotranspiration. The project would have a slightly beneficial effect upon low flows in the creek. For instance, the 10-year, 7-day low flow in Little Bear Creek is calculated to increase by 0.01 cfs to 4.09 cfs following project implementation.

Table 4
Peak Flows in Howell Creek Following Flow Diversions[1]

	Return Interval-Years			
	2	**10**	**100**	**Drainage Area (acres)**
Existing (cfs)	14.2	23.9	36.2	133
Post-Project (cfs)	29.4	41.0	52.8	320
% Increase	107%	72%	46%	140%

[1] At SR-9

3.0 LITTLE BEAR CREEK CHANNEL ASSESSMENT

This chapter reviews a recent study of stream habitat on Little Bear Creek. Existing channel geomorphology is also presented, based on a reconnaissance of the stream channel upstream and downstream of the Route 9 site.

3.1 Past Study

King County conducted a habitat assessment on Little Bear Creek (along with Swamp and North Creeks) from August to November 1999 with the following goals:

- Characterize the habitat quality, primarily for salmonids.
- Establish a baseline for future evaluation of trends in habitat quality and watershed functions.
- Assist in prioritizing areas for restoration and preservation.

The headwaters of Little Bear Creek are in an area south of Seattle Hill Road. The mainstem length is approximately 7-1/2 miles and the average gradient is approximately 0.8 percent. This area was originally dominated by forested wetlands but is currently undergoing conversion to residential development. The stream still has riparian wetlands with several active beaver ponds. Land use in the upper basin is primarily rural, with numerous horse farms throughout the subbasin. The upper mainstem of the creek has a predominantly young, deciduous riparian forest with several riparian wetlands. Below Maltby Road, land use is predominantly suburban, with the riparian zone narrow and broken throughout. The lower mainstem of the stream runs parallel to SR-522, a major four-lane commuter highway. The creek is heavily impacted with a poor quality riparian corridor and extensive suburban development. The lower portion of the creek runs through the commercial portion of downtown Woodinville before flowing into the Sammamish River.

As part of King County’s stream habitat study (King County, 2001), the mainstem of Little Bear Creek was assessed. The creek was divided into 14 segments that were similar in channel morphology and surrounding land use characteristics. Segments 6 and 7 correspond with the reach along the Brightwater project. Segment 6 extends from the inflow of Howell Creek upstream to 228th Street SE. Segment 7 extends from 228th Street SE upstream to 216th Street SE, about 1/4 mile north of the north boundary of the Route 9 site. Data from basin condition analyses and habitat assessments in the report are summarized below.

3.1.1 Riparian Integrity

Segments 6 and 7 have less than 40 percent forest riparian cover; the remaining riparian vegetation includes shrubs, tall herbaceous species, and vegetation associated with landscaped, residential property. The riparian vegetation has changed from the natural coniferous-dominated forest cover to landscaped areas, herbaceous vegetation, shrubs, various invasive species, and only minimal natural riparian forest cover. Note that the stream survey conducted for the Brightwater project (Section 4) noted a full riparian cover across the upper half of Segment 7.

3.1.2 Large Woody Debris (LWD)

LWD performs critical functions in forested lowland streams, including flow energy dissipation, streambank protection, streambed stabilization, sediment storage, and instream cover and habitat diversity. LWD recruitment potential depends heavily on riparian corridor quality and size.

Segments 6 and 7 both have less than 150 pieces of LWD/km, which is considered the low end of natural abundance ranges. More significant than the decreased LWD volume and abundance for Segments 6 and 7 is the lack of larger “key” pieces of LWD. Large pieces of LWD are important for anchoring debris jams, which have significant effects on pool size. LWD-influenced physical changes are typically followed by biological changes. The physically induced biological influences of LWD are substantial. Fish populations have been shown to decline rapidly following LWD removal.

3.1.3 Channel Morphology

Bankfull width to depth ratios (BFW:BFD) for Segments 6 and 7 are 8 and 12, respectively. The National Marines Fisheries Services defines a BFW:BFD ratio of 10 or more to be indicative of “at risk” channels and/or channels that are not functioning properly.

High peak flows and increases in the duration of high-flow events cause more frequent bankfull, channel-forming events that increase streambank erosion, bedload transport, and streambed scour. Urbanizing streams tend to “over-widen” and incise as a result of more frequent bankfull flows, which can be seen with the BFW:BFD ratio. Segment 7 had the highest percentage of armored streambank of any of the segments. As mentioned in Section 4, the majority of this armoring is attributable to the two lengths of channel adjacent to SR-9 in this area.

3.1.4 Riffle, Pool, and Glide Habitat

Segments 6 and 7 proved to have riffle habitat below the optimum fraction of 40 to 60 percent. These segments do not have riffles that comprise more than 45 percent of the total stream habitat. Of the 14 segments studied along Little Bear Creek, Segment 6 was one of the lowest in quality riffles and Segment 7 was one of the highest in quality riffles.

Neither Segments 6 nor 7 had pool frequencies of 30/km or more, the value indicative of properly functioning conditions.

Glides are intermediate habitat units that have characteristics of both pools and riffles but provide little of the functional capabilities of either. Segments 6 and 7 have 55 to 45 percent glide habitat, respectfully.

The substantial reduction in quantity and quality of pool habitat is most likely due to cumulative effects of urbanization, which include changes in the natural hydrologic regime and reduced LWD recruitment due to loss of riparian integrity. Past studies have found that forced pool-riffle reach morphology changes to glide-dominated plane-bed morphology with the loss of instream LWD.

3.1.5 Habitat Quality Index

The Habitat Quality Index (HQI) for Segments 6 and 7 was 17 and 31, respectively. This corresponds to a rating of low to medium-low habitat quality. Low scores for LWD, low habitat complexity, and the dominance of glide habitats in the segments contributed to the overall low HQI scores. Despite the presence of forest riparian buffers in these segments, LWD quantities and pool frequencies remained relatively low, suggesting mechanisms of wood removal are occurring other than the absence of a recruitment source. The dominance of deciduous forest in the riparian corridor may account for the low LWD quantity and quality.

3.1.6 Biology

Juvenile coho and cutthroat were sighted throughout all of the segments. Spawning sockeye and coho were also observed during the mid-September through early November habitat assessments of Little Bear Creek.

3.1.7 Summary

Little Bear Creek lacks the complex habitat structure that is important for sustaining a long-term, diverse salmonid population. The stream's general condition of inadequate pool and riffle habitat (which are too few and of poor quality), is likely a result of the cumulative effects of the interruption of numerous natural processes (including LWD recruitment) and basinwide hydrologic buffering processes that interact to create these habitats.

3.2 Stream Channel Conditions

On June 10, 2003, a walking visual survey was conducted along Little Bear Creek in the vicinity of the Route 9 site. The survey began near the confluence of Unnamed Creek and extended 5,000 feet downstream to the vicinity of the SR-9/SR-522 Interchange. Notes were taken on the general condition of the stream channel, stream geomorphology and bottom composition, overhead canopy, and other related factors. Signs of active channel incision and bank erosion were noted. A total of four sediment samples were taken from the stream bottom for later grain size analysis. Channel width and depth were measured at periodic intervals.

3.2.1 Observations

The weather conditions were cloudy and dry. There had been no substantial rainfall the previous 3 days. The stream was flowing clear. The channel cross-sectional geometry was generally quite uniform in shape and mildly incised from 1 to 2 feet in depth, but occasionally as deep as 4 feet. There were very few oxbows or other secondary channels. The stream appeared to have only limited interaction with the overbank area. The channel banks were stable and well vegetated. There were occasional small gravel bars but signs of significant and active sediment transport through the system were not observed. LWD is mostly lacking and there was very limited habitat diversity within the channel.

Upstream of 228th Street the channel is low-gradient and mildly incised. It is relatively wide (10 to 18 feet, averaging about 16 feet) in relation to its channel depth (see Section 3.1.3) and is classified as a Rosgen F Type Channel (Rosgen, 1996). The stream is comprised primarily of a series of riffles through this section. The stream substrate is generally gravel up to 3 inches in diameter. There was generally a full canopy overhead and the trees were typically alder and cottonwoods. Some redds from the previous spawning season were still visible, but very few young fish were observed. About halfway between 228th and 233rd Streets, the stream velocity slowed noticeably, apparently due to a decreased gradient. Pools 1.5 to 2 feet deep were common. Sandy bottom substrate became common. The canopy opened up and became somewhat intermittent.

Downstream of 233rd Street there was very little stream canopy. Much of this area has been recently planted in native species as part of a restoration area developed by the Washington State Department of Transportation (WSDOT). Beaver activity in the form of chewed tree limbs was evident. The flow in the stream channel became a slow-moving pool that was in excess of 2 feet deep. The stream bottom consisted of fine silt with some gravel.

Most of the streambanks observed along this stretch of Little Bear Creek have not been armored. However, the banks of the stream are rip-rapped along the two sections that run immediately beside SR-9, a total length of about 900 feet (Figures 3a and 3b). Two other short sections of rip-rap were observed along the stream. Rock and log flow deflectors were installed at one of these locations at an unusually sharp bend in the stream. A low block wall has been installed along 30 feet of the right bank of the stream about 300 feet upstream of 233rd Street.

3.2.2 Channel Stability

The stream channel and associated riparian area showed extensive signs of cultural modifications. Most of the upper half of the stream segment that was field-reviewed had a nearly full canopy cover, but the tree cover was mostly alder and maple with few fir trees. In a few cases, the riparian cover had been replaced with lawn and related landscaping by the landowner. The streambanks were armored with rip-rap where the creek flows immediately alongside SR-9. Otherwise, bank protection measures were limited to several of the driveway bridges crossing the stream and to three short sections of the stream.

The depth of the stream channel was shallow, generally from 1 to 2 feet. No sudden drops in the channel bottom were encountered. There were no signs of nick points or other indications of serious channel incision. The channel has a generally rectangular cross section and the width between banks varies little, averaging about 16 feet. Channel bank erosion was observed at just two locations. Both were along short sections of the outer bend of the stream. At one of these sites, rocks and log deflectors were installed, presumably as a bank protection measure. There was some accumulation of sandy sediment observed in the vicinity of the 233rd Street bridge. However, there does not appear to be a substantial amount of sediment deposition along this portion of the creek. It is concluded that the reach of Little Bear Creek adjacent to and downstream from the Route 9 site resides within a stable channel with no sign of significant erosion.

Four samples of the stream bottom sediment were taken at the locations shown in Figures 3a and 3b. The samples were dried and the grain size distribution of each sample was determined by passing it through a series of standard sieves (Attachment B). There are a number of methodologies for estimating the potential for channel erosion using sediment grain size distribution. The Yang Method (Yang, 1996) and the Meyer-Peter/Mueller (MPM) Methods (Meyer-Peter and Mueller, 1948) for estimating incipient motion (mobilization) of sediment were applied to this evaluation. The Yang Method calculates a critical flow velocity, above which stream sediment is likely to be mobilized. The MPM Method calculates a critical flow depth, above which stream sediment may be mobilized. A summary of the methodologies is included in Attachment C. Sediment mobilization in a stream can be an indication of vulnerability to channel erosion and stream damage.

Table 5 shows the calculated critical flow velocities and depths that could trigger sediment movement in the reach of Little Bear Creek adjacent to the Route 9 site. The critical flow velocity in the creek varies between 2.7 and 4.5 feet per second. The critical flow depth varies from 1.6 to 3.1 feet. It should be emphasized that these methodologies are approximate, but the numbers suggest that sediment movement could occur in the channel at relatively modest flow velocities. The HSPF Model applied to Little Bear Creek (Section 2) calculates stream depth and velocity on a reach basis for purposes of channel conveyance calculations. It was found that the reach-level depth-velocity calculations of the model were too coarse to utilize with the site-specific incipient motion calculations in Table 5. Thus, it was not possible with the available data to estimate the magnitude of stream flow at which stream sediment may be mobilized in the creek.

TABLE 5
Critical Velocities and Depths at Selected Stream Locations
Stream Sediment Grain Size Data

Sample No.	S1	S2	S4	S5
D_{90} mm	41	70	62	35
D_{90} ft	0.135	0.230	0.203	0.115
D_{50} mm	20	41	35	15
D_{50} ft	0.066	0.135	0.115	0.049
Channel Slope (ft/ft)	0.007	0.007	0.007	0.006
Critical Velocity (ft/sec)	3.16	4.52	4.17	2.73
Critical Depth (ft)	1.72	3.08	2.71	1.56

4.0 PROJECT EFFECTS ON STREAM GEOMORPHOLOGY

Development within the Little Bear Creek Basin has impacted the stream, particularly its middle and lower reaches. The reach reviewed in this study is a quite uniform cross-section. There is relatively little LWD and the stream channel is generally lacking in complex stream habitat. Gravel bars are limited along this stretch of the creek and there does not appear to be substantial sediment deposition. The stream channel may be somewhat over-widened (Section 3.3.3). However, there are no signs of substantial incision of the channel bed. Other than short lengths along two outer bends, channel bank erosion was not observed.

The project would divert a number of small, upslope tributaries to the north and south, consolidating them with Unnamed and Howell Creeks, respectively. The area which would be occupied by the treatment plant is currently in commercial or industrial use. Only a small fraction of this area currently receives any stormwater management other than collection and rapid offsite conveyance of stormwater runoff. The project would provide stormwater treatment and detention. As a result, the project would reduce peak flows in Little Bear Creek, downstream of Howell Creek, by 1 percent or more. A very small increase in peak flows could occur in the reach upstream of Howell Creek if all of the project runoff was to be discharged at a single point within the reach. The project site has its long axis in a north-south direction, parallel to the creek. There are a number of existing culverts under SR-9. Thus, detained project stormwater could be released at multiple points to the creek, virtually eliminating any increase in post-project flow in this stretch.

The geomorphic, or channel-forming, processes in a stream are most heavily influenced by high-flow events when the sheer forces acting upon the channel substrate are the greatest. The high flows in Little Bear Creek would not increase as a result of the project; they would instead slightly decrease downstream from the project site. As a result, the project is unlikely to change the geomorphic conditions in the creek. The relatively stable channel conditions observed in this study are expected to continue after the project is completed. There may be a slight improvement in channel stability downstream of the project.

The flows in Unnamed and Howell Creeks would greatly increase as a result of the proposed diversions. The channels of both of these highly modified streams are proposed to be restored to more natural conditions. It is recommended that hydraulic studies be carried out for both these creeks as part of the design for their restoration. This will allow for the proper combination of slope, channel roughness, and channel shape to adequately handle the increased flows. In addition, flow depth and velocities in these channels can be more closely matched to provide fish habitat.

As part of the proposed studies, the hydraulic capacity of the Howell Creek culvert and the fish rearing pond arch culvert, both under SR-9, should be reviewed and upgrades recommended, as necessary. These culverts lie within WSDOT right-of-way and any proposed culvert modifications would require agency approval.

5.0 REFERENCES

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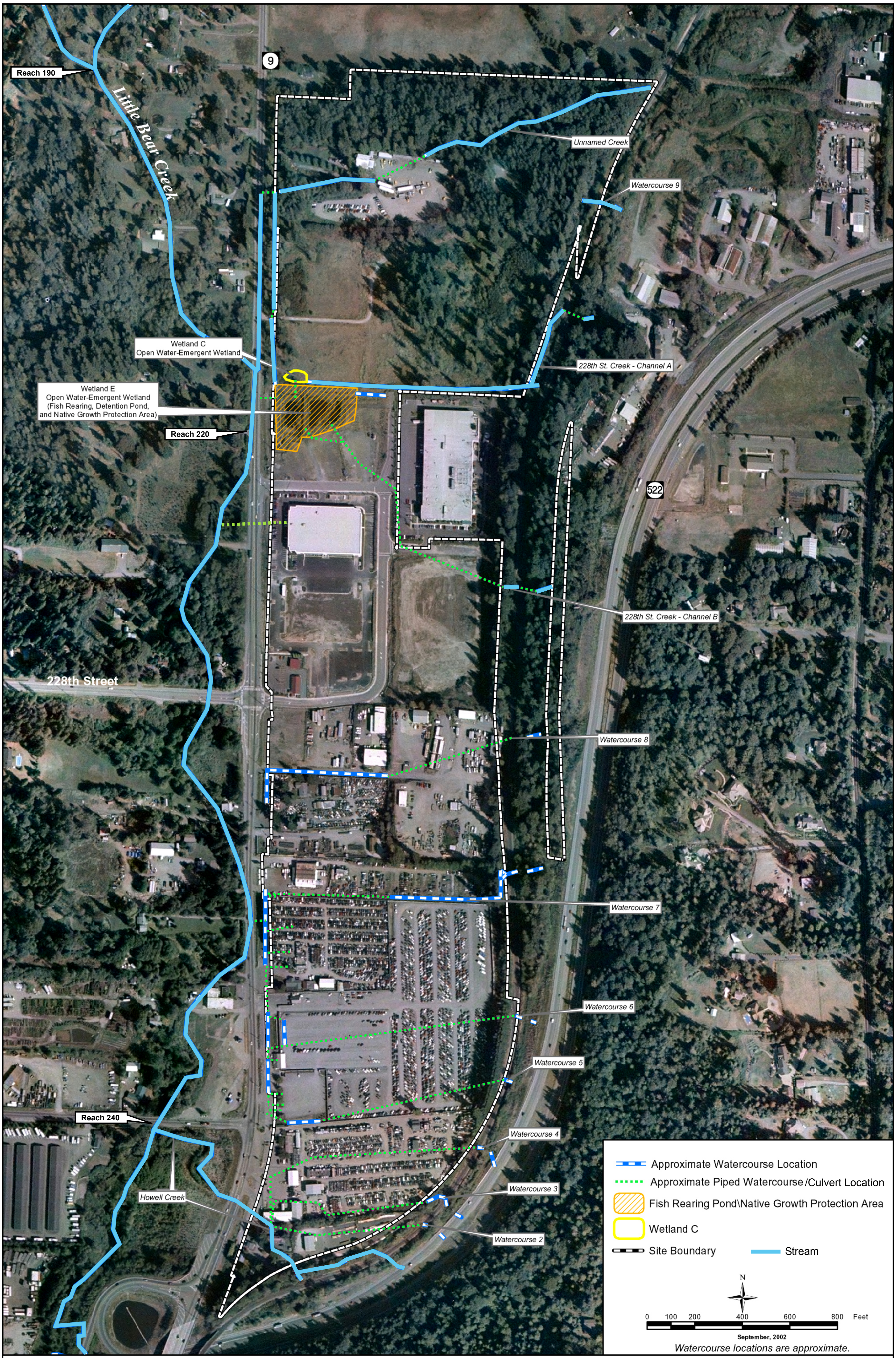

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Data Sources: Adolfson
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Figure 1
Surface Water Features - Route 9 Site

BRIGHTWATER REGIONAL WASTEWATER TREATMENT SYSTEM

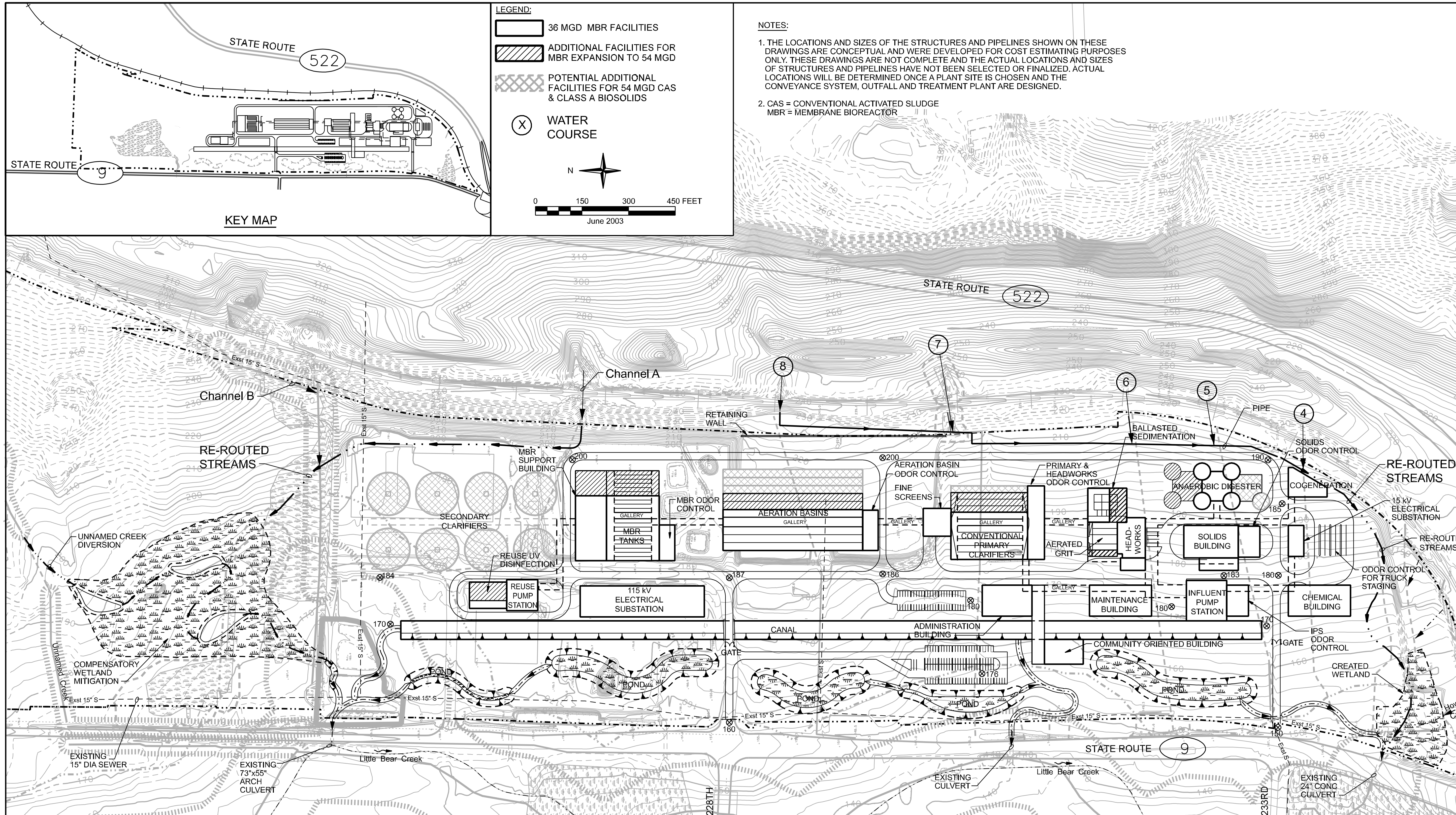

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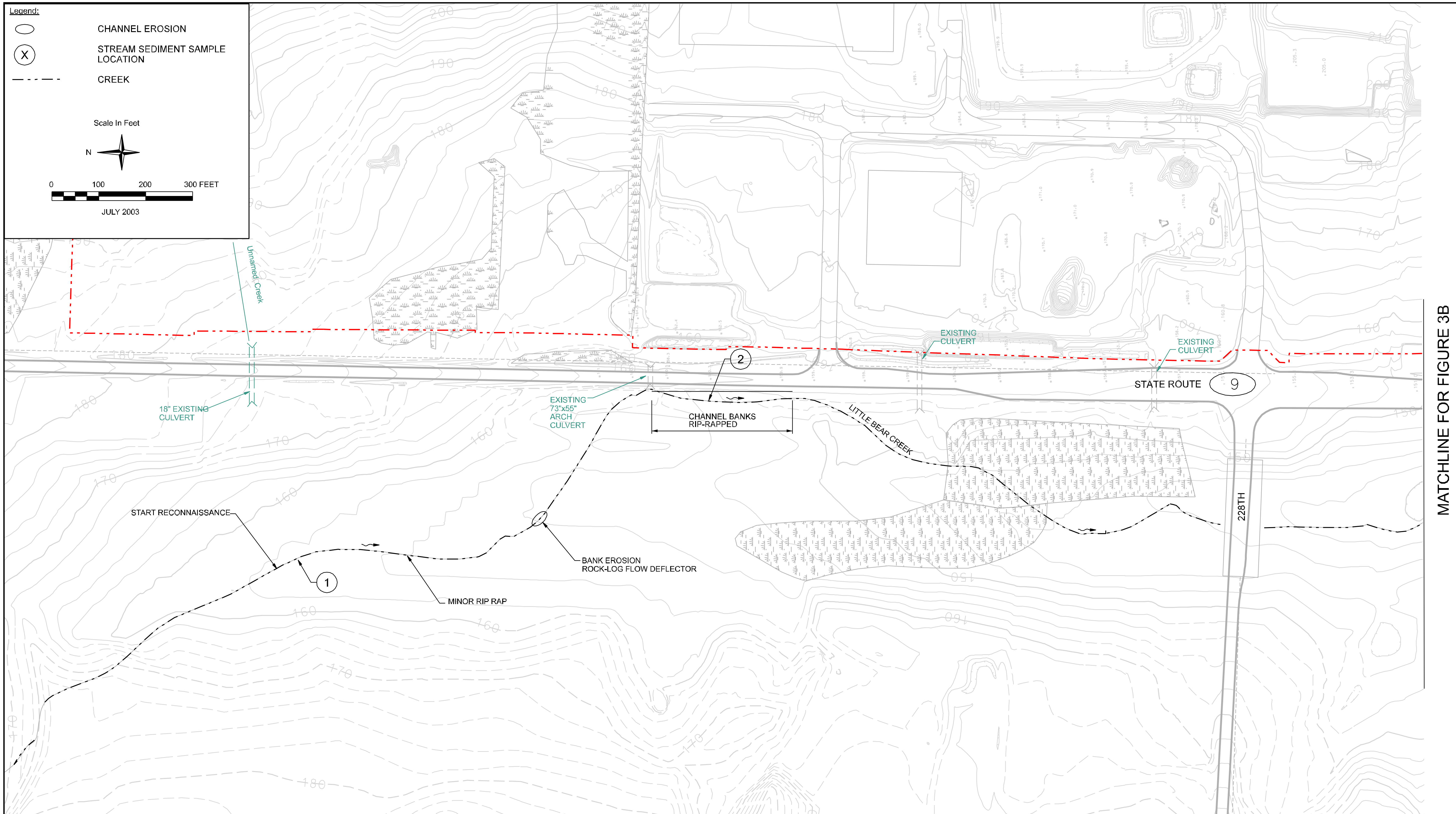
Figure 2
Conceptual Layout of the Stormwater System for the Route 9 Site

BRIGHTWATER REGIONAL WASTEWATER TREATMENT SYSTEM



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Wastewater Treatment Division

Prepared by: CH2M HILL
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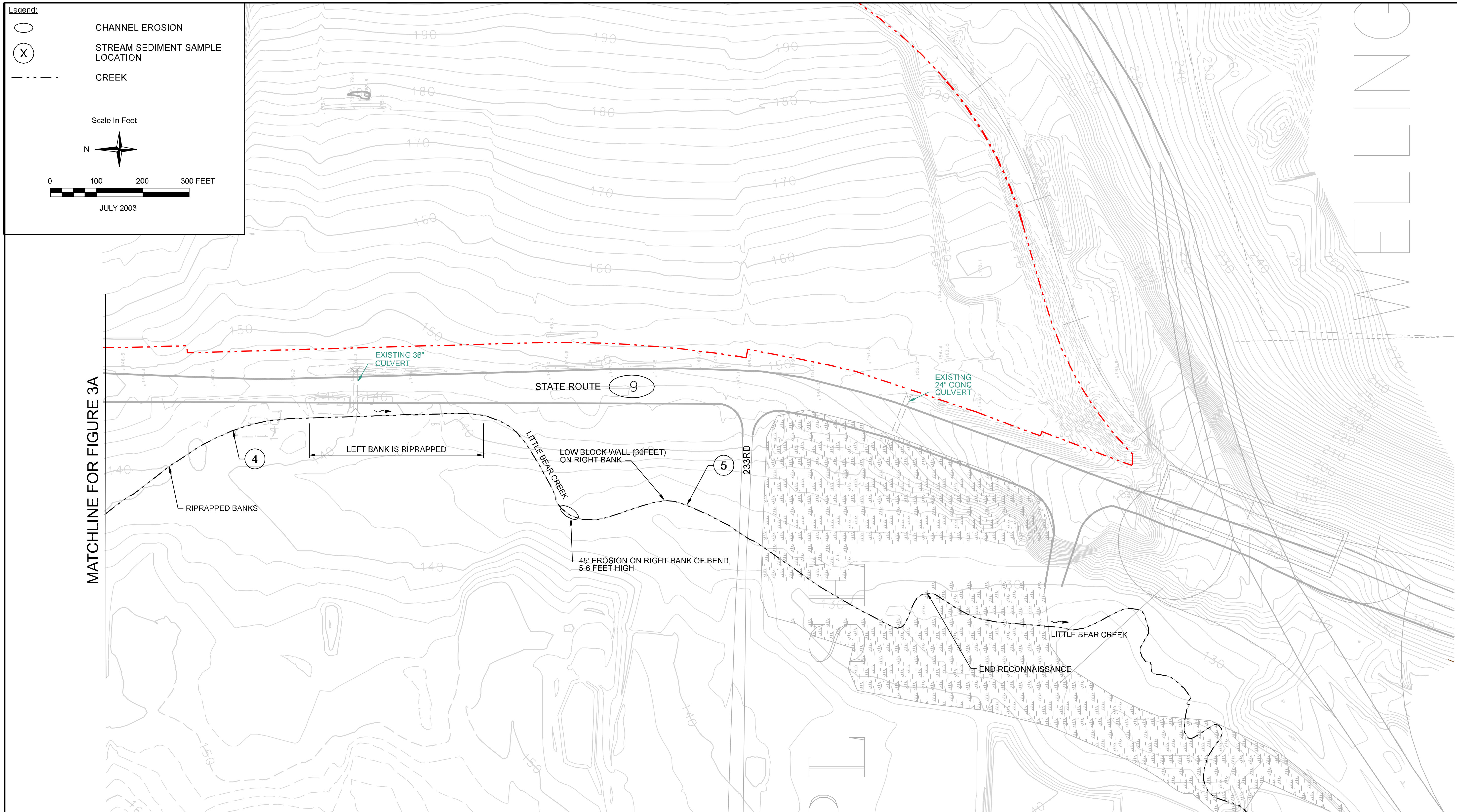
Figure 3a
Selected Channel Conditions Observed on Little Bear Creek

BRIGHTWATER REGIONAL WASTEWATER TREATMENT SYSTEM



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File Name: 176493.03.06_W052003009SEA_Geomorphology TM • Selected Channel Conditions Lil Bear Creek • 7/30/03 • rd

Figure 3b
Selected Channel Conditions Observed on Little Bear Creek

BRIGHTWATER REGIONAL WASTEWATER TREATMENT SYSTEM

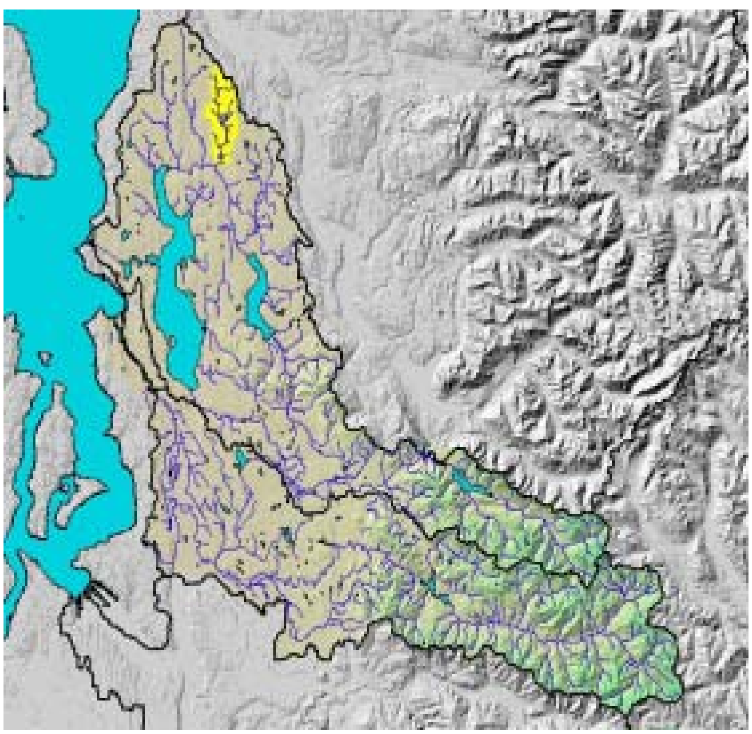
ATTACHMENT A

Characterization of Hydrology Surrounding Brightwater Regional Wastewater Treatment System – Proposed Route 9 Plant Site in the Little Bear Creek Drainage

(Prepared by Aqua Terra)

A Technical Memorandum:

Characterization of Hydrology Surrounding Brightwater Regional Wastewater Treatment System – Proposed Route 9 Plant Site in Little Bear Creek Drainage



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August 22, 2003

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1 Introduction

This Technical Memorandum is a document that describes the application of a recently completed comprehensive watershed model developed (December 2002) for the Little Bear Creek Subbasin. This modeling effort is part of the Freshwater program directed in Water and Land Resources Division, Scientific and Technical Support Section (WLRD-STSS). This memorandum will be finite in scope, however some refinements may occur during the model development and subsequent analyses conducted. This memo documents the method of approach, and analyses applied in characterizing and evaluating possible effects of the Route 9 proposed Site Plan to the local drainage system.

This memo presents a structure for the hydrologic modeling of Route 9 effects together with the use of the simulation developed for the entire Little Bear Creek subbasin. This structure includes the modeling framework and approach in Section 2, data requirements and availability in Section 3, and segmentation and characterization of the Route 9 site together with the model application procedures in Sections 4 and 5. All model applications typically uncover technical issues that require further data analyses. Consequently, any and all remaining issues to be resolved in this approach to modeling Route 9 are discussed in Section 6.

1.1 Purpose and Objectives

The purpose of the Route 9 modeling study is to provide hydrologic information on local drainage's entering and exiting Route 9 site, including Little Bear Creek downstream of the site for support in response to the DEIS comments, Permitting, CARA, and to the Brightwater Technical Team. Specific objectives of the study are to:

1. quantify the hydrologic behavior of the surface flow generated off-site upstream, on-site, and downstream off-site,
2. evaluate changes in land use as proposed for the Route 9 site including changes in the hydraulic routing of surface flows for mitigation purposes,

2 Modeling Method

The modeling methodology is based on the use of the continuous simulation model using HSPF (Hydrological Simulation Program Fortran). The modeling methodology makes use of the meteorologic, and hydrologic data collected in and near the subbasin together with topography, land use and stream channel information to provide long-term simulated streamflow time series, under existing conditions and proposed Plant Site configurations including re-routing of water courses around the site and other mitigation measures.

2.1 Framework and Approach

The base modeling framework was derived from the Little Bear Creek Watershed Model developed for the SWAMP (Sammamish, Washington, Modeling Project) project in the Freshwater Program in December 2002 and revised in May 2003. The modeling framework has been specifically developed to address each of the objectives in characterizing existing conditions and effects of the proposed Route 9 site conditions to the local drainage system. This updated model will be integrated back into the ensuing watershed modeling project to maintain the capability of characterizing the hydrology as well as the water chemistry for Little Bear Creek Subbasin for proposed analyses.

Briefly, the Little Bear Creek model was calibrated to the timeframe of water years 1999 through 2001 (October 1998 through September 2001) based on available (at the time) streamflow data at King County's Little Bear Creek gage at Highway 202 (gage number: 30A). Final calibration resulted in an overall acceptance of accuracy as defined by twelve metrics in the Little Bear Creek Calibration. Of significance, are over estimating of instantaneous storm flow rate peaks (winter and summer) by over 60 percent, but with the highest ten-percent of flows differing by less than ten percent. Summer storm events were under estimated by 12 percent with the lowest ten-percent of flow rates differing by less than 7 percent. Agreement between simulated and observed mean daily flow rates was calculated to be 0.92 (R-square of

0.92) based on the three years of data recorded. Further detail can be obtained in the Little Bear Creek Calibration Report revised draft (June 2003) (AQUA TERRA Consultants, 2003)

The existing model was re-segmented to provide the ability to individually characterize several local water courses and two streams entering and leaving the proposed site (as defined by Adolfson) not originally defined in the Little Bear Creek model in the SWAMP project. Using existing available information and field reconnaissance conducted by multiple parties, hydraulic conveyances were identified and defined to support the model re-segmentation (see Section 3.3).

3 Data Requirements and Availability

Estimation of flood frequencies and durations require multiple continuous time series of data. For water quantity modeling, this is limited to a few meteorological and surface water sources. Calibration of the model requires continuous local precipitation and stream flow in hourly or fifteen-minute increments, with the addition of a regional Pan Evaporation converted to Potential Evapotranspiration (PET) in daily accumulated increments. Upon calibration, local precipitation records are compared to the nearest long term observation station (typically greater than 40 years of hourly data). A coefficient of transformation is then computed and applied to the long-term data set for simulation in the local subbasin. In the subsequent sub-sections, descriptions of the data will pertain to long-term simulations not conducted in the calibration phase of the model development. Details in calibration techniques and data generation can be reviewed in the Little Bear Creek Calibration Report (AQUA TERRA Consultants, 2003).

3.1 Meteorological

Long-term precipitation data used was a composite of Everett precipitation (NWS 452675) and a gage operated by Snohomish County—Silver Lake (SI). Silver Lake precipitation data started in 1988, thus requiring the augmentation of data from Everett for long-term simulations. Based on ten years of overlapping observations, a coefficient of transformation derived from daily totals was estimated. Using this coefficient, Silver Lake data was back-filled starting in October 1948 and continuing through 1988. A similar transformation coefficient was calculated and applied to relate Silver Lake Precipitation data to local data observed in the subbasin. The coefficient of transformation on Silver Lake data is 1.05, and was applied to the entire composite time-series for simulations.

Potential Evapotranspiration data is derived from Pan Evaporation data either measured at an observatory (Class-A Pan) in Puyallup or augmented either by filling in gaps either resulting from no measurements taken, or extending the data set after the observation station was shut down in 1993. For the created time series of Pan Evaporation data a coefficient of 0.78 is applied to convert it to Potential Evapotranspiration in Little Bear Creek subbasin. Detail on how these data are created can be referenced in the Little Bear Creek Calibration Report (AQUA TERRA Consultants, 2003). For location of Silver Lake and Little Bear gages, see Figure 3-1.

3.2 Water Quantity

For Little Bear Creek, surface water quantity data was used for calibration purposes only and not required for long term simulations in support of generating flood frequencies and durational analyses. For more information on gages used in calibration and long-term simulations, see Figure 3-1 and Table 3-1 below.

3.2.1 Surface Water

Gage data exists only for Little Bear Creek mainstem. No data exist for local inflows and outflows of the proposed site. However, it is identified in King County's Staff Recommend Sampling and Analysis Plan (SAP) to install continuous gage recorders in the two tributaries believed to be perennial (King County 2003).

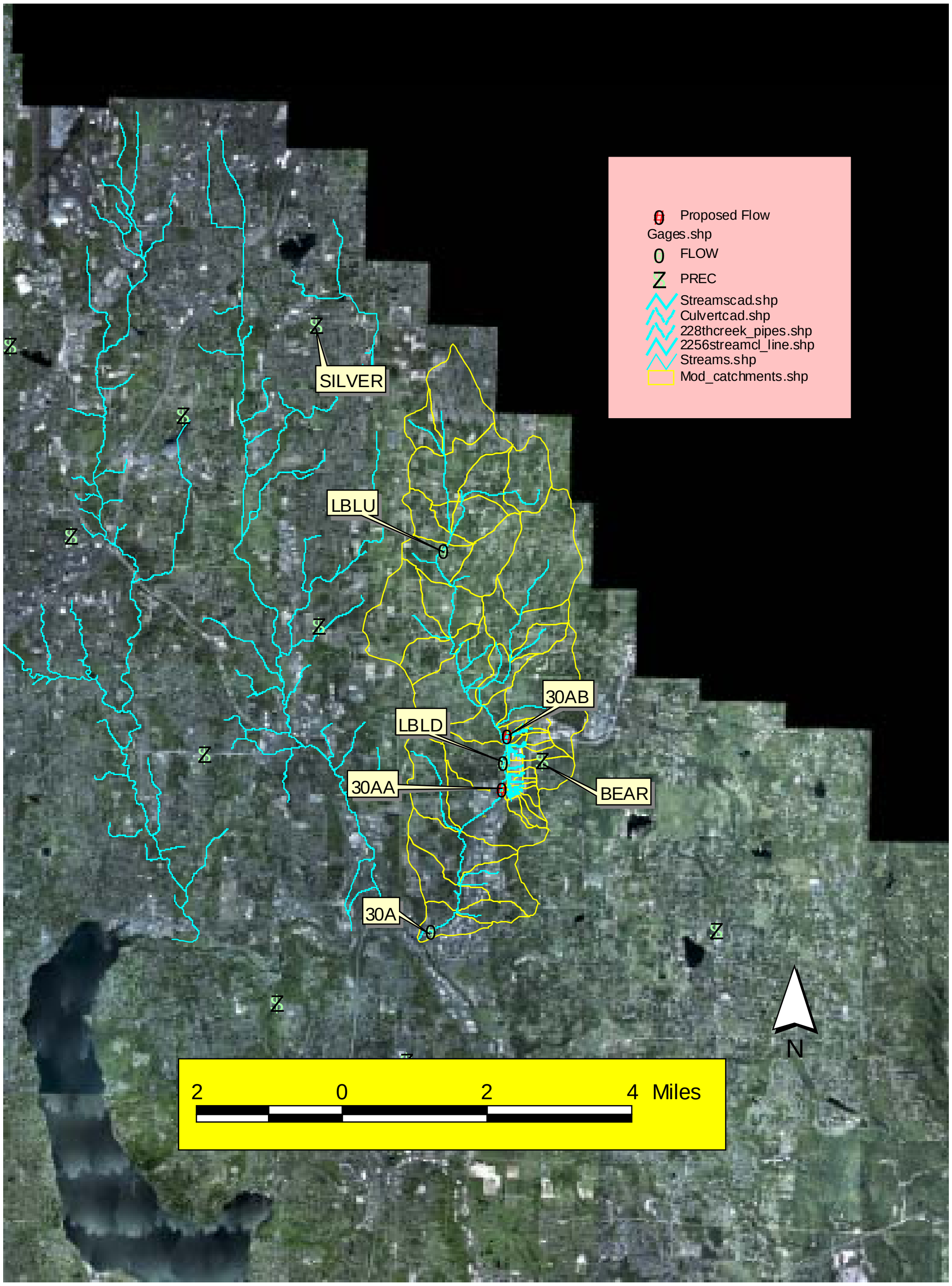


Figure 3-1 Stream and Precip Gages near Little Bear Creek

Table 3-1 Available Data Used in Model Simulations

Gage Name	Dates Available	Type	Comments
30A	Oct-1998 to Present	Flow	King County Gage, gage used for primary calibration
LBLD	Mar-2000 to Present	Flow	Snohomish County Gage, short period of record was available during calibration.
LBLU	June-2000 to April-2002	Flow	At the time no rating curve was available
BEAR		Precip	King County, short term precipitation station installed for WTD- I & I project
Silver	Oct-1948 to Present	Precip	Composite time series. Prior to 1988 data is filled with NWS Everett Precipitation Data with scaler.
30AA	N/A	Flow	Proposed site location from SAP
30AB	N/A	Flow	Proposed site location from SAP

3.3 Conveyance Hydraulics

Conveyance hydraulics consists of the stream channels, roadside ditches, culverts, pipes, ponds, stormwater detention facilities, and other drainage features that either bring runoff and streamflow to the Route 9 site, transport it across the site, or assist it in exiting the site. Conveyance hydraulic information was used in the HSPF model to compute streamflow and runoff routing to, through, and from the Route 9 site. It was specifically used to create the FTABLEs (stage-storage-discharge tables) in the HSPF model.

3.4 Existing

The existing conveyance hydraulics were determined based on the following sources:

1. field investigations on 26 March and 14 April 2003
2. Hydraulic Report, SR 9: SR522 to Clearview, WSDOT, June 1993
3. aerial photos provided by Adolfson Associates, March 2003
4. Engineering and Drainage Report for Binding Site Plan, Woodinville Business Park Lots 1,2,3,4, and 5, Lovell-Sauerland & Associates, October 2000

Culvert data collected from these sources is shown in Table 3-2. For some culverts inlet and/or outlet elevations had to be estimated.

The culvert data were input to the Federal Highway Administration's HY8 culvert analysis computer program to compute the stage-discharge relationship for each culvert. Inlet control was assumed for all culverts.

Open channel data were collected from the field investigations and are summarized in Table 3-3 below. Stream channel lengths and elevations were estimated from maps.

The open channel data were input to AQUA TERRA's XS2 computer program to compute the open channel stage-storage-discharge relationship for each channel. XS2 uses Manning's equation to compute discharge.

Most Brightwater drainage pathways have culverts at the downstream end of the open channel reach. At high flows the culverts act as downstream controls on the flow in the reach. The flow cannot exceed the culvert capacity. For each model reach that included a culvert, the culvert stage-discharge relationship was compared with the open channel stage-discharge relationship and the smaller of the two was used in creating an FTABLE for that stream reach.

Table 3-2 Culvert Data

	RCHRES	culvert dia (in)	culvert type	inlet elev	outlet elev	length	location
Rte 9 Ditch N of Unnamed Cr	319	12	CMP	173.4	172.8	36	crossed over Unnamed Cr culvert
Unnamed Cr	211	30	CMP	236.7	236.6	30	farm drainage from north
	212	36	CONC	277.2	277.1	32	RR tracks
	213	24	CONC	274	273.9	32	RR tracks
	221	18	CMP	207.4	191.7	389	upstream of landscaping yard
	321	18	CONC	170.7	170.1	47	Rte 9
Channel A: 228th St Cr	222	24	CONC	245.5	244.8	32	RR tracks
	223	24	CONC	239.0	238.3	32	RR tracks
	322	no culvert					open channel to fish pond
	323	see Stock Pot detention pond					detention pond
	326	see fish rearing pond					fish rearing pond
	325	73x55	ARCH CMP	149.0	148.0	96	Rte 9
Channel B	224	36	CONC	232.0	230.3	126	RR tracks
	324	36	CMP	210.6	155.0	1558	pipe under roadway
Woodinville Business Park	327	see pipe storage					underground detention tank
	328	see detention vault					underground detention vault
Water Course 8	237	18	PLASTIC	229.4	181.2	579	RR tracks
	337	no culvert					open channel to Rte 9
Water Course 7	236	24	CONC	230.0	229.0	32	RR tracks
	336	2 - 6	PLASTIC	180.0	142.6	526	pipes along auto yard boundary
Water Course 6	235	30	CONC	230.0	229.0	32	RR tracks
	335	12	PLASTIC	210.0	152.0	1053	pipe under Fitz yard

	RCHRES	culvert dia (in)	culvert type	inlet elev	outlet elev	length	location
Water Course 5	234	18	CONC	220.0	219.0	32	RR tracks
	334	12	PLASTIC	213.0	152.0	947	pipe under Fitz yard
	338	36	CONC	135.6	133.0	105	Rte 9 (inlet and outlet submerged)
Water Course 4	233	18	CONC	215.0	214.0	32	RR tracks
	333	18	PLASTIC	200.0	160.0	1053	pipe under Fitz yard
Water Course 3	238	18	STEEL	211.0	210.0	32	RR tracks
	239	18	CMP	198.1	156.0	1000	pipe under Fitz yard
Water Course 2	232	24	CONC	210.0	209.0	32	RR tracks
	332	18	PLASTIC	200.0	154.0	695	pipe under Fitz yard
Howell Cr	231	36	CONC	165.2	162.4	95	RR tracks
	331	18	CMP	156.3	151.2	68	
	339	24	CONC	138.7	135.3	150	Rte 9

Table 3-3 Open Channel Data

Stream	RCHRES	bottom width	top width	height	up elev	down elev	length (ft)	length (mi)	downstream end
Rte 9 ditch N	319	2	6	2	190.0	160.0	2000	0.38	Rte 9 fish ladder culvert
Unnamed Cr	211	1	6	3	250.0	220.0	500	0.09	confluence with 212 and 213
	212	1	6	3	400.0	220.0	2000	0.38	confluence with 211 and 213
	213	1	6	3	400.0	220.0	2000	0.38	confluence with 212 and 213
	221	2	6	3	220.0	207.4	400	0.08	upstream of landscaping yard
	321	2	10	4	191.7	170.7	421	0.08	Rte 9
Channel A	222	1	10	10	400.0	245.5	3000	0.57	RR tracks
	223	1	10	10	400.0	239.0	3000	0.57	RR tracks
	322	1	8	3	238.3	162.0	1263	0.24	open channel to fish pond

Stream	RCHRES	bottom width	top width	height	up elev	down elev	length (ft)	length (mi)	downstream end
	323							0.00	fish pond
	325	2	6	2			100	0.02	Rte 9 fish ladder culvert
Channel B	224	1	10	10	500.0	232.0	3000	0.57	RR tracks
	324	1	10	6	230.3	210.6	58	0.01	pipe under roadway
Water Course 8	237	1	10	10	500.0	229.4	3000	0.57	entering property
	337	1	6	2	181.2	151.0	621	0.12	open channel to Rte 9
Water Course 7	236	1	10	10	500.0	230.0	3000	0.57	RR tracks
	336	2	8	4	223.4	160.0	500	0.09	pipes along auto yard boundary
Water Course 6	235	1	10	10	500.0	230.0	3000	0.57	RR tracks
	335	1	1	1	210.0	152.0	1053	0.20	pipe under Fitz yard
Water Course 5	234	1	10	10	500.0	220.0	3000	0.57	RR tracks
	334	1	1	1	213.0	152.0	947	0.18	pipe under Fitz yard
	338	2	8	5	150.0	135.5	800	0.15	Rte 9 (inlet and outlet submerged)
Water Course 4	233	1	10	10	400.0	211.0	2000	0.38	RR tracks
	333	1	1	1	200.0	160.0	1053	0.20	pipe under Fitz yard
Water Course 3	238	1	10	10	400.0	211.0	2000	0.38	RR tracks
	239	1	1	1	198.0	156.0	1000	0.19	pipe under Fitz yard
Water Course 2	232	1	10	10	400.0	210.0	2000	0.38	RR tracks
	332	2	12	6	209.0	200.8	80	0.02	pipe under Fitz yard
Howell Cr	231	2	4	2	500.0	165.2	3000	0.57	entering property
	331	2	4	2	162.4	151.2	300	0.06	
	339	3	8	3	150.0		700	0.13	Rte 9

The Woodinville Business Park was found to have four water storage facilities. These are:

1. Stock Pot detention pond
2. fish rearing pond
3. business park underground storage tank
4. business park underground storage vault

The Stock Pot detention pond, underground storage tank, and storage vault were modeled based on the stage-storage-discharge data provided by the Lovell-Sauerland report. Based on the information in the report, it appears that each of these three detention facilities handles only local runoff from the business park area.

The fish rearing pond was modeled using the drawings provided in the Lovell-Sauerland report and by computing the discharge via the fish ladder using the weir equation.

3.4.1 Proposed

The proposed conveyance hydraulics are based on the assumption that the upstream off-site flow conveyance system will not change. The on-site system will be altered based on the following assumptions:

1. Channels A and B will be routed to join Unnamed Creek.
2. Unnamed Creek will be routed down the east side of Rte 9 to the 73-inch by 55-inch arch CMP before crossing the highway to join Little Bear Creek.
3. The fish rearing pond will be removed.
4. The Stock Pot detention pond and the two Woodinville Business Park vaults will be removed.
5. Water Courses 1-8 will go to Howell Creek.
6. All new or revised conveyances are open channels.
7. The two major culverts (325 and 339) under Rte 9 will remain as is.
8. Discharge from the Brightwater stormwater ponds will go directly to Little Bear Creek in reach 220, adjacent to the site.

The Brightwater stormwater pond was modeled using stage-storage-discharge data produced by CH2M HILL using the Department of Ecology's WWHM2 .

3.5 Land Use

Land use in the Little Bear Creek HSPF model is described in detail in the Little Bear Creek Calibration Report (AQUA TERRA Consultants, 2003). To summarize that report, the King County GIS coverage (with 1995 land use data) was converted into 36 pervious land segments and four impervious land segments for the Little Bear Creek watershed. Each pervious land segment represents a different hydrologic response to rainfall and is comprised of a combination of soils, land slope, vegetative cover, and land use. The four impervious land segments represent low density residential development, high density residential, commercial/industrial, and roads, respectively.

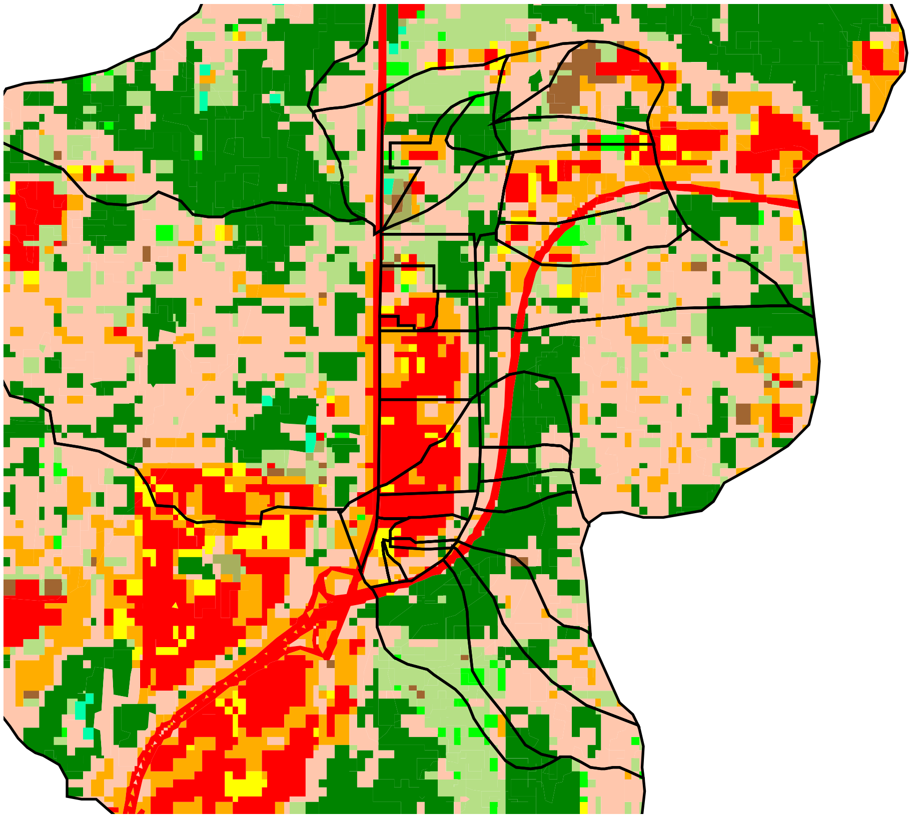


Figure 3-2 Existing Land Use Used in Creation of the HSPF UCI File for BWRWTS Route 9

The forty land cover categories are derived from multiple land use themes, of which land use is the primary source. In Figure 3-2 above, land use is summarized into seven general categories: 1) highly impacted, roads (Red), 2) High density mixed commercial/residential (yellow), 3) Medium Density Residential (Mustard), 4) Low Density Residential (Peach), 5) Forest (Dark Green), 6) Grass (Greens), 7) recently cleared, Bare Soil (Brown). Catchment delineations are shown in black.

For the Route 9 site the above pervious and impervious land segmentation was used with the land use divided into the subcatchments described in Section 4.

The post-project land use was modeled using the existing conditions land use data with the following changes:

1. The area draining to the Brightwater stormwater pond was based on 64 acres (24.06 acres of outwash commercial/industrial landscape and 33.44 acres of impervious surfaces plus 6.5 acres of pond surface area) used in the WWHM2 report to size the pond.
2. The remaining Route 9 site area (23.60 acres) south of the area draining to the Brightwater stormwater pond is assumed to be reforested and to drain to Howell Creek
3. All other pre-construction impervious surfaces within the Route 9 site were assumed to be replaced with pervious surfaces.

4 Segmentation and Characterization

Segmentation of the Route 9 site drainages was required to determine the flow statistics (frequency and duration) for each of the streams entering the Route 9 site and the existing drainage patterns within the site.

The subcatchment delineation and hydraulic conveyance system are based on this segmentation. Characterization of the subcatchments and the conveyance system provided the necessary land and stream channel respective input to the HSPF model.

4.1 Subcatchment Delineation

The Route 9 site, the upslope contributing area north and east of the site, and the area between the site and Little Bear Creek were delineated into thirty-five subcatchments. These subcatchments and their drainage area are listed in Table 4-1.

Table 4-1 Brightwater-related Subcatchments – Existing Conditions

Subcatchment	Area (acres)
210	15.39
211	8.43
212	23.51
213	11.14
220	319.92
221	6.61
222	29.83
223	22.11
224	53.26
230	4.77
231	31.78
232	38.43
233	26.32
234	7.85
235	6.94
236	17.00
237	137.46
238	26.16
239	0.75
319	20.37
321	14.28
322	13.68
323	11.05
324	4.83
327	9.21
328	1.07
331	1.12
332	3.53
338	4.50
334	6.55
335	12.79
336	13.72
337	18.82
333	0.75
339	3.80

Figure 4-1 shows the locations of these subcatchments and Figure 4-2 shows catchments overlaid on Ortho image taken in 2000.

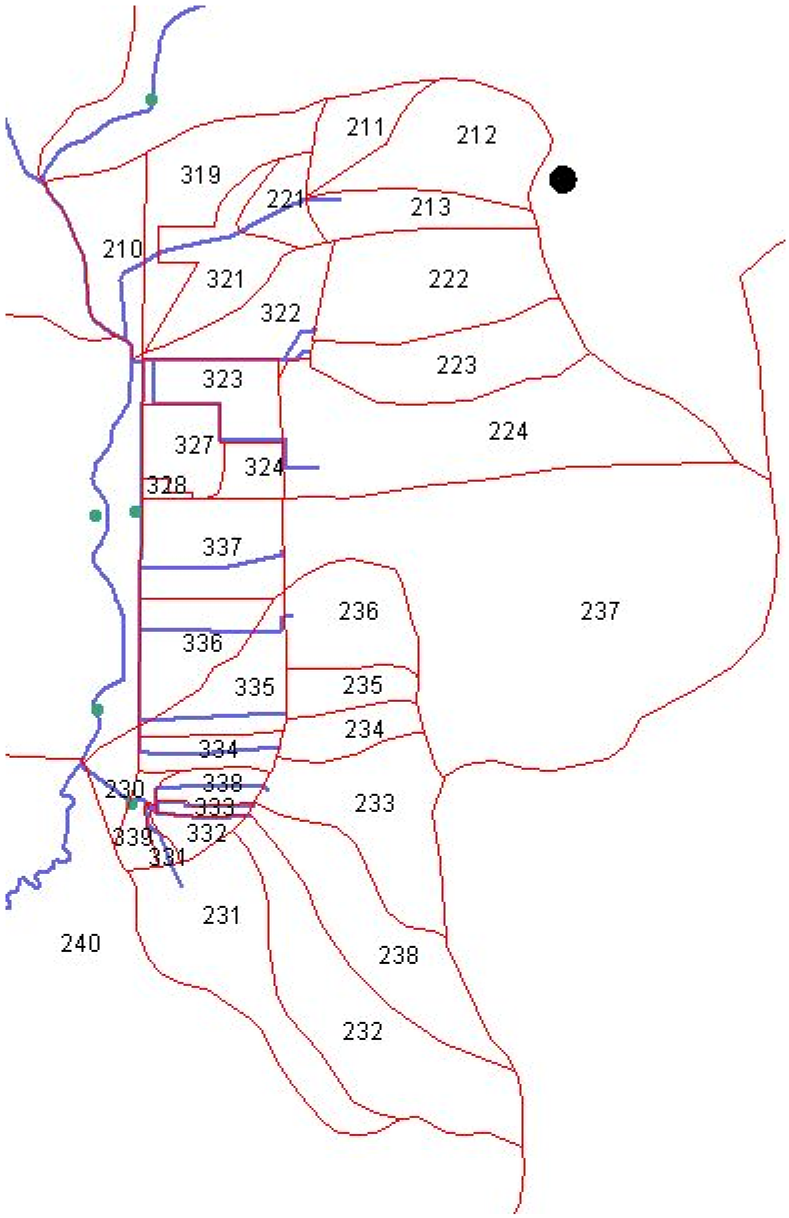


Figure 4-1 Subcatchment Delineation

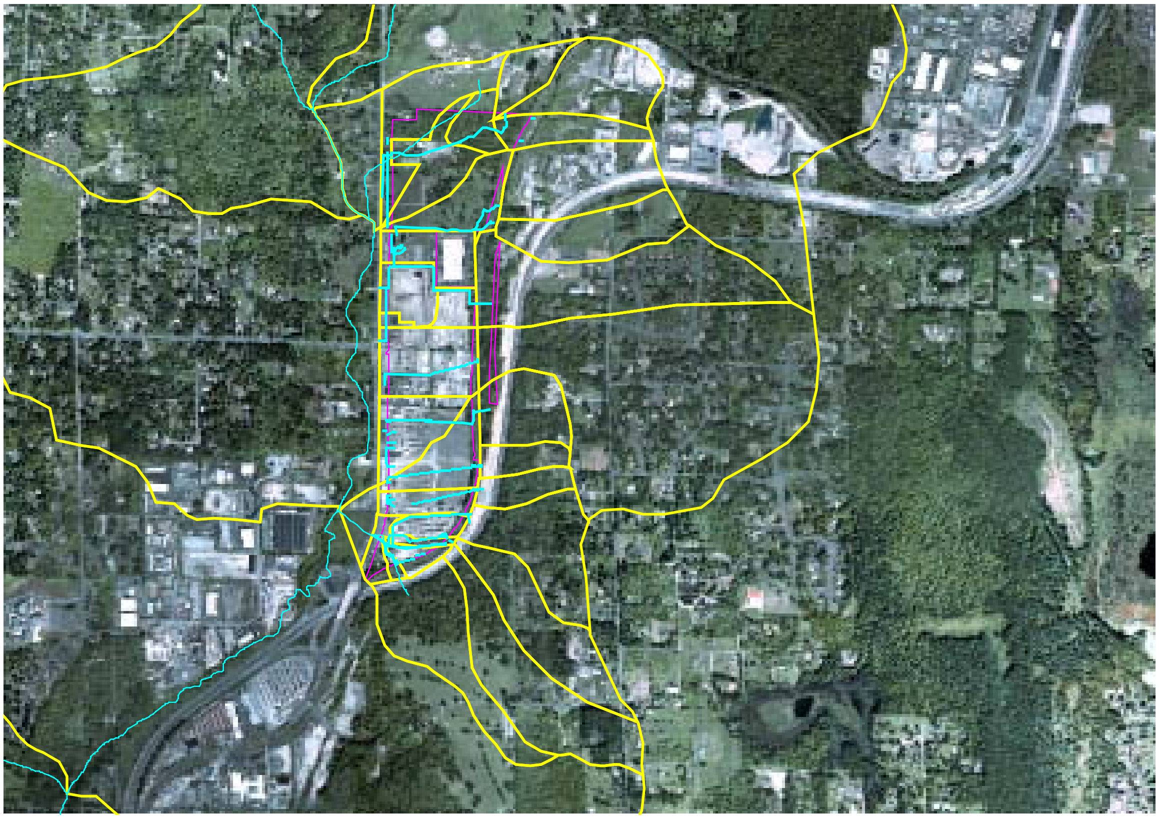


Figure 4-2 Subcatchment Delineation (yellow), identified water courses (blue), and identified Site boundary (purple) displayed on Orthographic Image collected in 2000

For the proposed conditions the subcatchments 239, 323, 324, 327, 328, and 332-338 were deleted. These subcatchments were replaced with subcatchment 349 representing the Brightwater facility and subcatchment 348 representing the collector reach on the southeast side of the facility site. The proposed conditions subcatchments and their drainage areas are listed in Table 4-2.

Table 4-2 Brightwater Proposed Conditions Subcatchments

Subcatchment	Area (acres)
210	15.39
211	8.43
212	23.51
213	11.14
220	319.92
221	6.61
222	29.83
223	22.11
224	53.26
230	4.77
231	31.78
232	38.43
233	26.32
234	7.85
235	6.94

236	17.00
237	137.46
238	26.16
239	0.00
319	20.37
321	14.28
322	13.68
323	0.00
324	0.00
327	0.00
328	0.00
331	1.12
332	0.00
338	0.00
334	0.00
335	0.00
336	0.00
337	0.00
333	0.00
339	3.80
348	23.60
349	57.50
Brightwater Pond	6.50

4.2 Hydraulic Conveyance System Defined

The existing hydraulic conveyance system is described in Section 3.4. Figure 4-3 provides a schematic of how the existing conveyance system routes streamflow and runoff through the Route 9 site to Little Bear Creek.

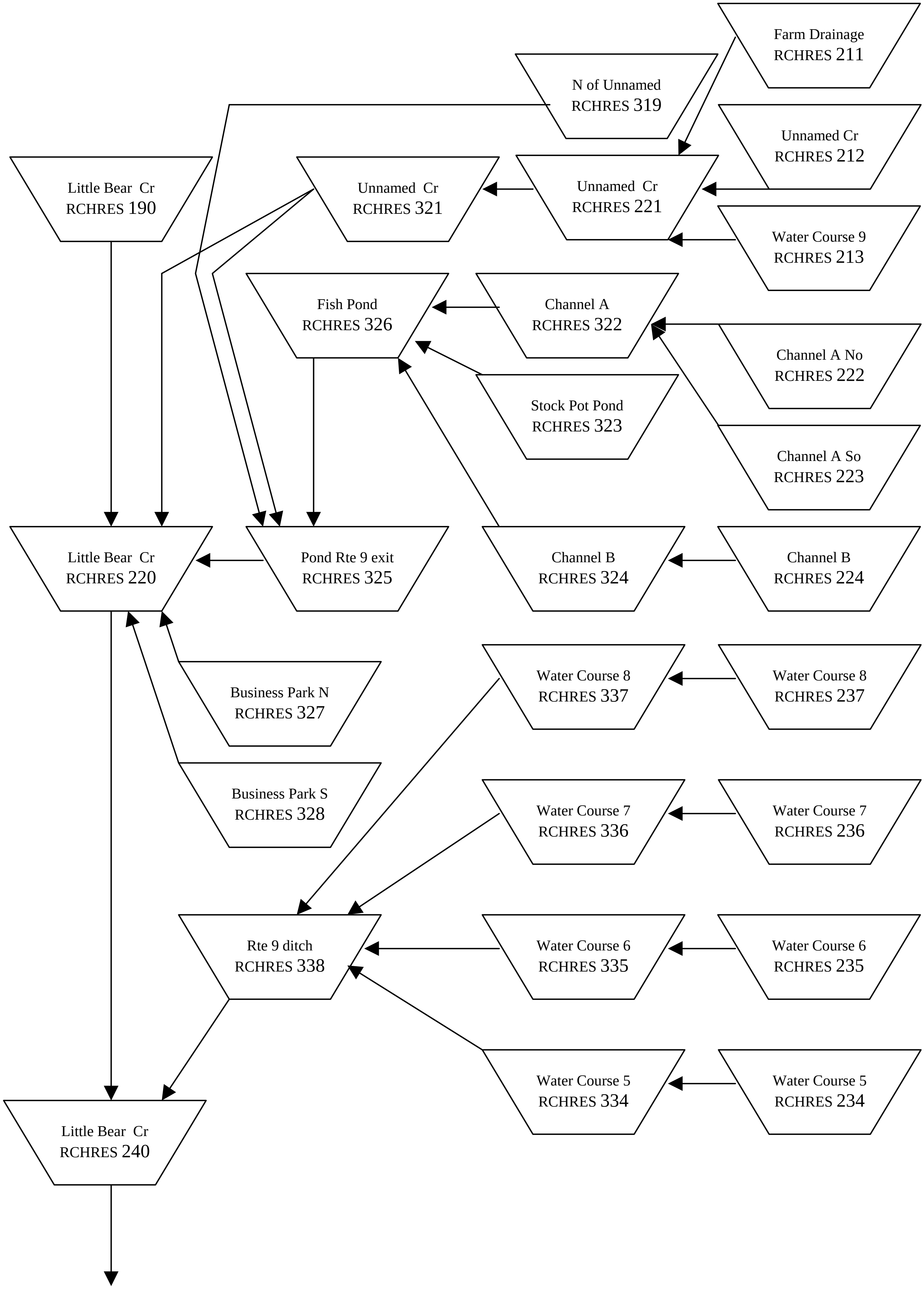


Figure 4-3 Brightwater HSPF Routing Schematic: Existing Conditions

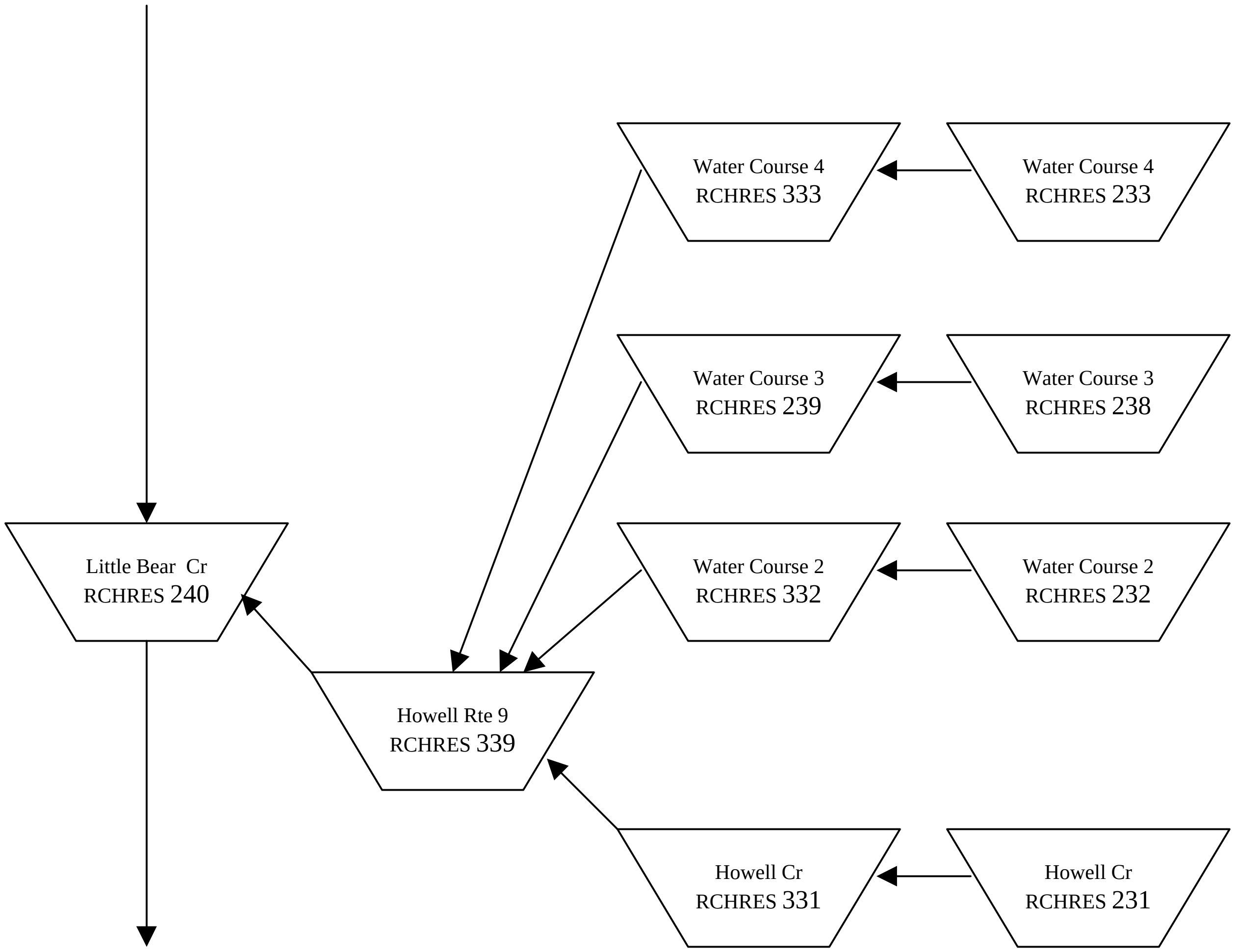
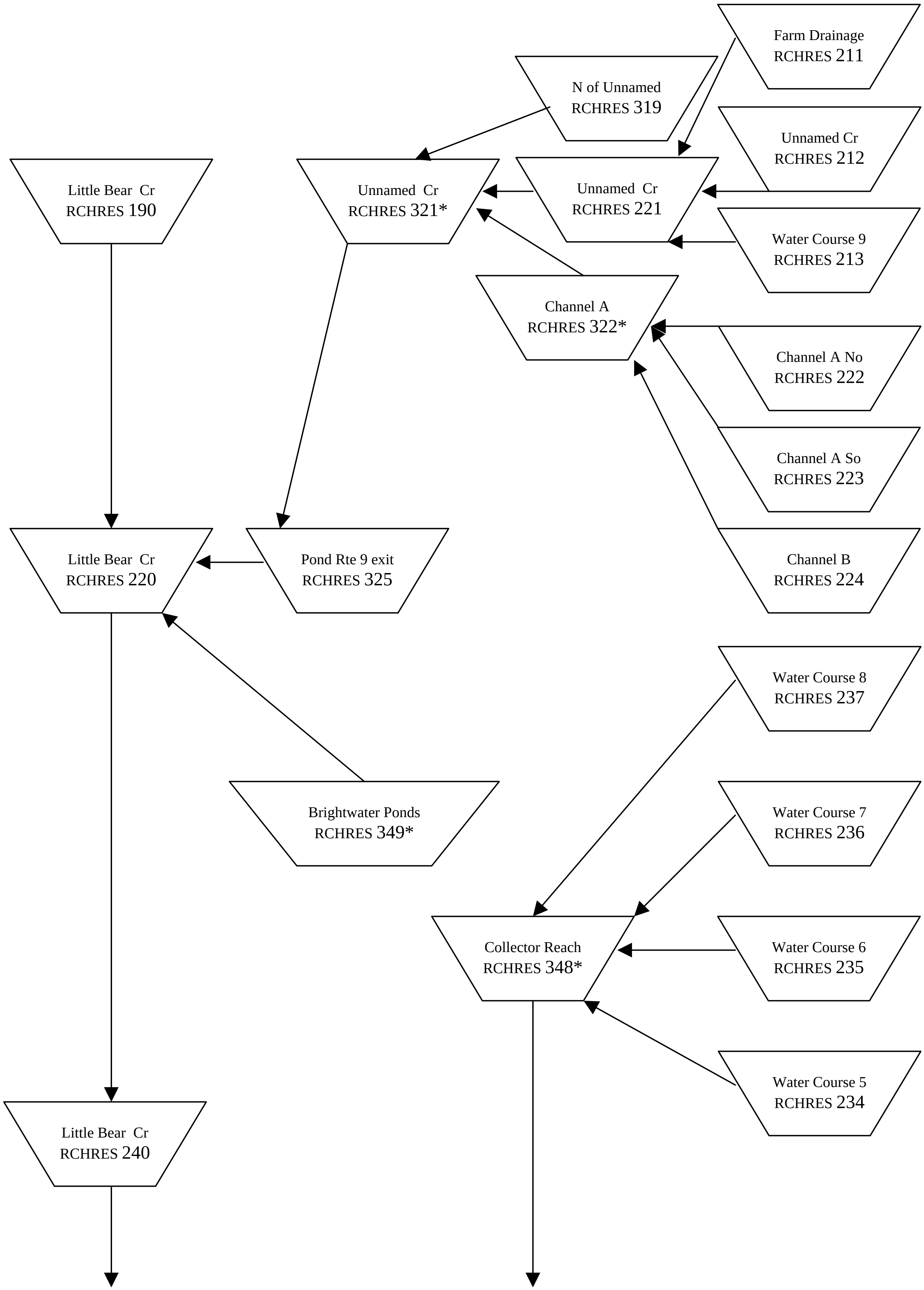


Figure 4-3 Brightwater HSPF Routing Schematic: Existing Conditions


Farm Drainage
RCHRES 211
N of Unnamed
RCHRES 319
Unnamed Cr
RCHRES 212
Little Bear Cr
RCHRES 190
Unnamed Cr
RCHRES 321*
Unnamed Cr
RCHRES 221
Water Course 9
RCHRES 213
Channel A
RCHRES 322*
Channel A No
RCHRES 222
Channel A So
RCHRES 223
Little Bear Cr
RCHRES 220
Pond Rte 9 exit
RCHRES 325
Channel B
RCHRES 224
Water Course 8
RCHRES 237
Brightwater Ponds
RCHRES 349*
Water Course 7
RCHRES 236
Collector Reach
RCHRES 348*
Water Course 6
RCHRES 235
Water Course 5
RCHRES 234
Little Bear Cr
RCHRES 240

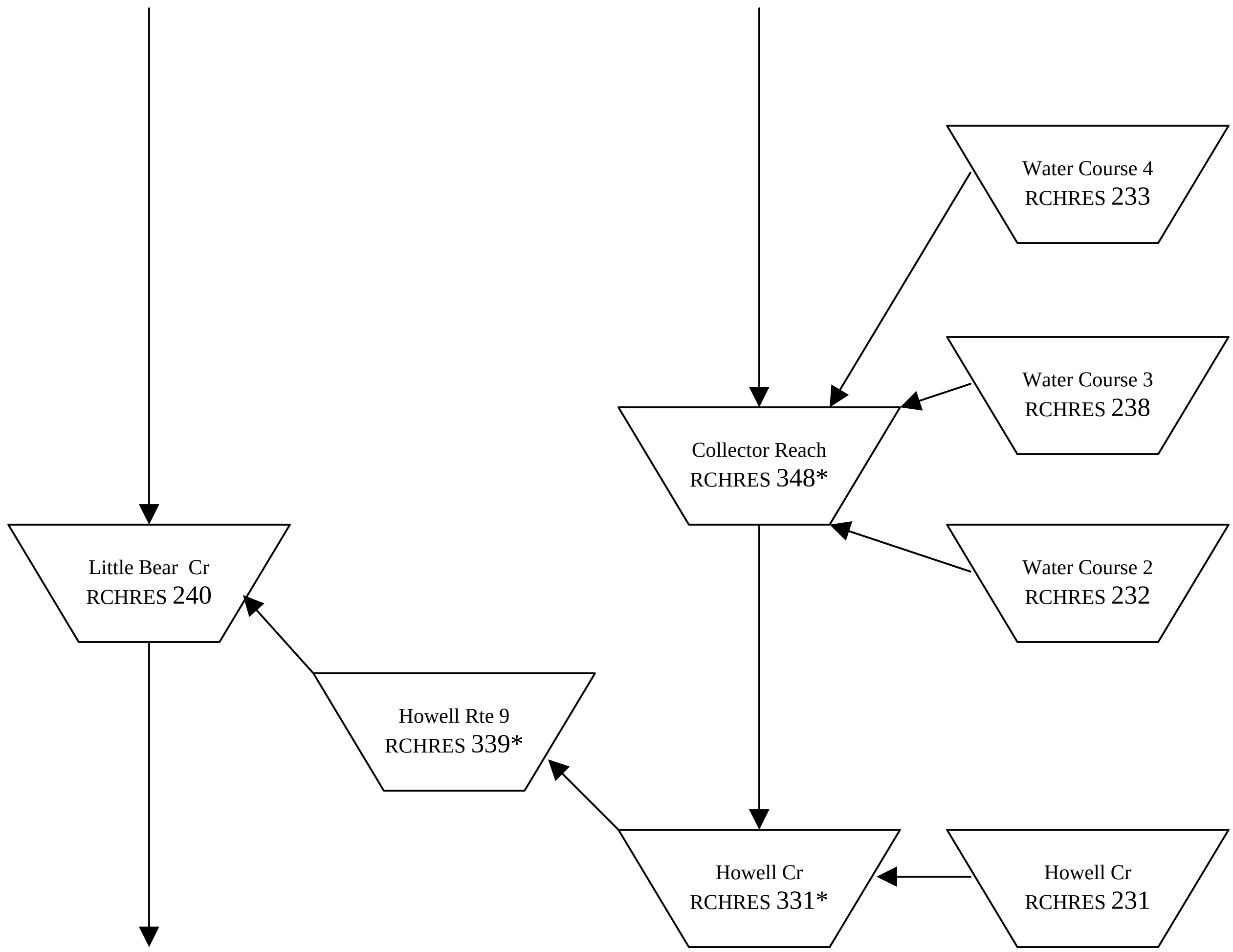


Figure 4-4 Brightwater HSPF Routing Schematic: Proposed Conditions

Note that the HSPF model reaches marked with an asterisk (*) are new or have been modified from the existing conditions model.

5 Model Application and Analysis

Model application and analysis were based on the original Little Bear Creek HSPF model developed for King County as part of the SWAMP project. As described in Section 4 above, the subbasins that comprise the Route 9 site were further subdivided to provide detailed hydrology results for each stream entering the site and for the drainage channels leading to Little Bear Creek.

The HSPF model provides 53 years of 15-minute simulated flow at multiple locations selected by the user. Analysis of the simulated flow included flow frequency (Log Pearson Type III, Bulletin 17B) and flow duration (USGS GenScn).

5.1 Existing Conditions

The HSPF model provides 53 years of 15-minute simulated flow at 13 drainages entering the Route 9 site from the east and two drainages from the north. The model includes the entire Little Bear Creek watershed. The HSPF stream reach immediately upstream of the confluence with Unnamed Creek is Little Bear reach 190. Between the Unnamed Creek confluence and the Howell Creek confluence is Little Bear reach 220. Downstream of the Howell Creek confluence is Little Bear reach 240. Five channels/culverts drain from the Route 9 site to Little Bear Creek as shown in Table 5-1.

Table 5-1 Drainage to Little Bear Creek from Route 9 site

Stream	RCHRES	Location
Channels A&B	325	Rte 9 sta 206+04
Business Park	327	Rte 9 sta 200+35
Business Park	328	Rte 9 sta 195+51
Rte 9 ditch	338	Rte 9 sta 184+23
Howell Cr	339	Rte 9 sta 172+84

5.1.1 Flow Frequency Results

Flow frequency results (1.005, 2, 5, 10, 25, and 100-year floods) were computed for each stream entering and leaving the Route 9 site plus Little Bear Creek upstream (reach 190), adjacent (reach 220), and downstream (240) of the Route 9 site. The results are shown in Table 5-2.

Table 5-2 Existing Conditions Flow Frequency

Drainage	DSN	Location	Return Period (years)	Flow (cfs) 1.005	2	5	10	25	100
Little Bear Creek	7190	upstream		134	261	351	416	505	653
	7220	adjacent		173	329	436	513	618	790
	7240	downstream		203	392	514	600	714	894
Unnamed Creek culvert	7321	at Rte 9		1.8	4.1	5.6	6.5	7.7	9.5
Channels A&B culvert	7325	at Rte 9		5.6	14.4	20.4	24.6	30.4	39.6
Sum of Howell Creek + Water Courses 1 thru 8	7231	at RR tracks		13.2	32.8	43.5	50.2	58.4	70.1
Culvert near Fitz Auto	7338	at Rte 9		16.9	34.4	43.5	49.1	55.9	65.6
Howell Creek culvert	7339	at Rte 9		5.2	14.4	20.0	23.9	28.8	36.2
Howell Cr + Water Course 1	7031	at RR tracks		1.0	3.4	4.9	5.8	7.0	8.7
Water Course 2	7032	at RR tracks		2.1	6.2	8.6	10.2	12.2	15.1
Water Course 3	7038	at RR tracks		1.4	4.1	5.6	6.6	7.8	9.4
Water Course 4	7033	at RR tracks		1.1	3.5	4.9	5.7	6.6	7.9
Water Course 5	7034	at RR tracks		0.3	1.0	1.4	1.7	2.0	2.5
Water Course 6	7035	at RR tracks		0.4	1.2	1.8	2.1	2.6	3.2
Water Course 7	7036	at RR tracks		0.6	2.3	3.2	3.8	4.5	5.4
Water Course 8	7037	at RR tracks		6.8	14.1	17.7	19.8	22.3	25.8
Rte 9 Ditch Drainage N of Unnamed	7319	Rte 9 culvert		0.4	0.9	1.1	1.3	1.6	2.0
Channel A north branch	7022	at RR tracks		2.5	6.9	9.2	10.7	12.4	14.8
Channel A south branch	7023	at RR tracks		1.2	3.7	5.1	6.1	7.3	9.1
Channel B	7024	at RR tracks		2.5	7.5	10.5	12.4	14.9	18.5
Woodinville Business Park north	7327	at Rte 9		0.2	1.2	1.6	1.9	2.1	2.3
Woodinville Business Park south	7328	at Rte 9		0.02	0.09	0.17	0.24	0.36	0.62

Little Bear Creek stream channel depths were computed from the Little Bear Creek flow frequencies. These results are shown in Table 5-3.

Table 5-3 Existing Conditions Depth Frequency

Drainage	DSN	Location	Return Period (years)	Depth (ft) 1.005	2	5	10	25	100
Little Bear Creek	7190	upstream		2.5	4.0	4.8	5.2	5.7	6.5
	7220	adjacent		3.1	4.1	4.8	5.2	5.6	6.1
	7240	downstream		3.7	5.2	6.1	6.6	7.4	8.1

Little Bear Creek stream channel velocities were computed from the Little Bear Creek flow frequencies. These results are shown in Table 5-4.

Table 5-4 Existing Conditions Velocity Frequency

Drainage	DSN	Location	Return Period (years)	Velocity (fps) 1.005	2	5	10	25	100
Little Bear Creek	7190	upstream		3.9	4.1	4.3	4.6	4.9	5.2
	7220	adjacent		3.5	3.7	3.7	3.7	3.7	3.7
	7240	downstream		4.3	5.1	5.2	5.3	5.3	4.8

5.1.2 Flow Duration

Flow duration results were plotted using GenScn software. Flow duration plots are provided in Appendix A.

5.1.3 Mean Monthly Flows

Mean monthly flows were computed for Little Bear Creek at reach 240; Channels A and B at Rte 9; Howell Creek at Rte 9; and Channel A (north branch), Channel A (south branch), Channel B, Water Courses 2-8, and Howell Creek at the railroad tracks on the upstream side of the Route 9 site. Mean monthly flows are shown in Table 5-5.

Table 5-5 Existing Conditions Mean Monthly Flow

Drainage	DSN	Location	Flow (cfs)					
			Jan	Feb	Mar	Apr	May	Jun
Little Bear Creek	7240	downstream	31.54	25.99	26.69	19.43	13.94	11.81
Unnamed Creek	7321	at Rte 9	0.24	0.20	0.22	0.17	0.14	0.12
Channels A&B	7325	at Rte 9	0.64	0.52	0.54	0.40	0.31	0.27
Howell Creek + Water Courses 1 thru 4	7339	at Rte 9	0.51	0.42	0.43	0.32	0.23	0.20
Howell Cr + Water Course 1	7031	at RR tracks	0.12	0.10	0.10	0.08	0.06	0.05
Water Course 2	7032	at RR tracks	0.15	0.12	0.12	0.09	0.06	0.05
Water Course 3	7038	at RR tracks	0.09	0.08	0.08	0.06	0.04	0.03
Water Course 4	7033	at RR tracks	0.10	0.08	0.08	0.06	0.05	0.04
Water Course 5	7034	at RR tracks	0.03	0.02	0.03	0.02	0.02	0.01
Water Course 6	7035	at RR tracks	0.03	0.02	0.02	0.02	0.01	0.01
Water Course 7	7036	at RR tracks	0.06	0.05	0.06	0.04	0.03	0.03
Water Course 8	7037	at RR tracks	0.55	0.45	0.45	0.32	0.22	0.19
Channel A north branch	7022	at RR tracks	0.14	0.11	0.11	0.08	0.06	0.05
Channel A south branch	7023	at RR tracks	0.09	0.08	0.08	0.06	0.04	0.04
Channel B	7024	at RR tracks	0.21	0.17	0.18	0.13	0.10	0.08

Drainage	DSN	Location	Flow (cfs)					
			Jul	Aug	Sep	Oct	Nov	Dec
Little Bear Creek	7240	downstream	8.53	7.57	7.80	11.32	21.96	28.01
Unnamed Creek	7321	at Rte 9	0.09	0.08	0.08	0.10	0.16	0.21
Channels A&B	7325	at Rte 9	0.20	0.18	0.19	0.28	0.50	0.59
Howell Creek + Water Courses 1 thru 4	7339	at Rte 9	0.15	0.13	0.13	0.19	0.36	0.45
Howell Cr + Water Course 1	7031	at RR tracks	0.04	0.03	0.03	0.04	0.07	0.10
Water Course 2	7032	at RR tracks	0.04	0.03	0.03	0.05	0.10	0.13
Water Course 3	7038	at RR tracks	0.02	0.02	0.02	0.03	0.07	0.08
Water Course 4	7033	at RR tracks	0.03	0.03	0.03	0.03	0.07	0.09
Water Course 5	7034	at RR tracks	0.01	0.01	0.01	0.01	0.02	0.03
Water Course 6	7035	at RR tracks	0.01	0.01	0.01	0.01	0.02	0.03
Water Course 7	7036	at RR tracks	0.02	0.02	0.02	0.02	0.04	0.06
Water Course 8	7037	at RR tracks	0.13	0.12	0.13	0.19	0.40	0.50
Channel A north branch	7022	at RR tracks	0.04	0.03	0.04	0.07	0.13	0.14
Channel A south branch	7023	at RR tracks	0.03	0.02	0.03	0.04	0.07	0.09
Channel B	7024	at RR tracks	0.06	0.06	0.06	0.08	0.16	0.19

5.1.4 Low Flow

Low flow was computed in terms of the 10-year, 7-day low flow. The USGS SWSTAT (Surface Water time series Statistics) program, version 4.1, was used to compute 7-day low flows and then calculate the 10-year frequency of occurrence. Although the HSPF model results show 10-year, 7-day low flows of less than 0.1 cfs for many of the smaller stream channels, it should be assumed that these streams run dry during these periods. Table 5-6 shows the 10-year, 7-day low flows for existing conditions.

Table 5-6 Existing Conditions 10-Year 7-Day Low Flow

Drainage	DSN	Location	Flow (cfs)
Little Bear Creek	7240	downstream	4.08
Channels A&B	7325	at Rte 9	0.085
Howell Creek + Water Courses 1 thru 8	7339	at Rte 9	0.070
Howell Cr + Water Course 1	7031	at RR tracks	0.018
Water Course 2	7032	at RR tracks	0.019
Water Course 3	7038	at RR tracks	0.014
Water Course 4	7033	at RR tracks	0.014
Water Course 5	7034	at RR tracks	0.004
Water Course 6	7035	at RR tracks	0.004
Water Course 7	7036	at RR tracks	0.009
Water Course 8	7037	at RR tracks	0.067
Channel A north branch	7022	at RR tracks	0.013
Channel A south branch	7023	at RR tracks	0.012
Channel B	7024	at RR tracks	0.030

5.2 Proposed Conditions

The HSPF model for the proposed conditions (Brightwater Route 9 site) is based on the hydraulic conveyance system described in sections 3.4 and 4.2 and the land use discussed in section 4.1.

5.2.1 Flow Frequency Results

Flow frequency results (1.005, 2, 5, 10, 25, and 100-year floods) were computed for Unnamed Creek (including Channels A&B) and Howell Creek leaving the Route 9 site plus the collector reach for water courses 2-8; discharge from the Brightwater stormwater pond; and Little Bear Creek upstream (reach 190), adjacent (reach 220), and downstream (240) of the Route 9 site. The Little Bear Creek results are shown in Table 5-7.

Table 5-7 Proposed Conditions Flow Frequency

Drainage	DSN	Location	Return Period	Flow (cfs)					
			(years)	1.005	2	5	10	25	100
Little Bear Creek	8190	Upstream		134	261	351	416	505	653
	8220	Adjacent		174	328	435	512	615	786
	8240	Downstream		197	379	497	580	689	863
				Change (cfs)					
Little Bear Creek	8190	Upstream		0	0	0	0	0	0
	8220	Adjacent		0	0	-1	-1	-2	-4
	8240	Downstream		-6	-13	-17	-20	-25	-32
				Change (%)					
Little Bear Creek	8190	Upstream		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	8220	Adjacent		0.2%	-0.1%	-0.2%	-0.3%	-0.4%	-0.5%
	8240	Downstream		-3.1%	-3.3%	-3.4%	-3.4%	-3.5%	-3.5%

There was no change in the Little Bear stream reach (190) upstream of the confluence with Unnamed Creek, as the upstream area is not affected by the proposed Brightwater facility. In the Little Bear reach (220) immediately adjacent to the Brightwater there is a slight (less than 1 percent) decrease in peak flow rates as a result of the combined runoff from Unnamed Creek and the Brightwater stormwater pond discharge. Downstream of the confluence with Howell Creek the Little Bear reach 240 shows a larger decrease in flow frequencies. This is due to the elimination of the Rte 9 ditch and culvert in front of Fitz Auto. In the existing condition this ditch and culvert collects flows from water courses 5 through 8 plus runoff from the area between the railroad tracks and Rte 9. In the proposed scenario these water courses will be routed to the collector reach (348) and sent to Howell Creek. Howell Creek flows will increase (see Table 5-10), but this is more than offset by the Route 9 site stormwater detention and the timing of the discharge from the stormwater detention pond relative to the flows in Little Bear Creek. These changes cause a decrease in Little Bear Creek peak flows downstream of the confluence (reach 240) compared to existing conditions.

Little Bear Creek proposed stream channel depths were computed from the Little Bear Creek flow frequencies. These results are shown in Table 5-8.

Table 5-8 Proposed Conditions Depth Frequency

Drainage	DSN	Location	Return Period (years)	Depth (ft) 1.005	2	5	10	25	100
Little Bear Creek	8190	upstream		2.5	4.0	4.8	5.2	5.7	6.5
	8220	adjacent		3.1	4.1	4.8	5.2	5.6	6.1
	8240	downstream		3.6	5.1	6.0	6.5	7.2	8.0
				Change (ft)					
Little Bear Creek	8190	upstream		0.0	0.0	0.0	0.0	0.0	0.0
	8220	adjacent		0.0	0.0	0.0	0.0	0.0	0.0
	8240	downstream		-0.1	-0.1	-0.1	-0.1	-0.2	-0.1
				Change (%)					
Little Bear Creek	8190	upstream		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	8220	adjacent		0.2%	0.0%	-0.1%	-0.2%	-0.1%	-0.2%
	8240	downstream		-1.4%	-2.0%	-1.8%	-2.0%	-2.2%	-1.0%

The decrease in Little Bear Creek depth is less than 0.1 feet (2%) in reach 220 and approximately 0.2 feet (2%) in reach 240. These results are consistent with the flow frequency results.

Little Bear Creek stream channel velocities were computed from the Little Bear Creek flow frequencies. These results are shown in Table 5-9.

Table 5-9 Proposed Conditions Velocity Frequency

Drainage	DSN	Location	Return Period (years)	Velocity (fps) 1.005	2	5	10	25	100
Little Bear Creek	8190	upstream		3.9	4.1	4.3	4.6	4.9	5.2
	8220	adjacent		3.5	3.7	3.7	3.7	3.7	3.7
	8240	downstream		4.3	5.1	5.2	5.3	5.3	4.9
				Change (fps)					
Little Bear Creek	8190	upstream		0.0	0.0	0.0	0.0	0.0	0.0
	8220	adjacent		0.0	0.0	0.0	0.0	0.0	0.0
	8240	downstream		0.0	0.0	0.0	0.0	0.0	0.1
				Change (%)					
Little Bear Creek	8190	upstream		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	8220	adjacent		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	8240	downstream		-1.1%	-0.7%	-0.1%	-0.1%	0.0%	2.3%

The change in Little Bear Creek stream velocities is less than 0.1 feet per second (fps). There is no increase in peak velocities in reach 220 and a small decrease and increase (1-2%) in reach 240, depending on the return period.

The HSPF model flow depth and velocity results shown in Table 5-8 and Table 5-9, respectively, are approximate and are presented more to show magnitudes rather than hydraulically accurate calculations. This is because the depths and velocities are computed based on the stage-storage-discharge (FTABLE) information for Little Bear Creek and are average reach values. A detailed hydraulic study of the Little Bear Creek stream channel is recommended prior to making any decisions regarding the impact of the Route 9 site runoff on Little Bear Creek channel depths and velocities.

Howell Creek and Unnamed Creek proposed conditions flow frequency results are shown in Table 5-10.

Table 5-10 Howell and Unnamed Creek Proposed Conditions Flow Frequency

Drainage	DSN	Location	Return Period	Flow (cfs)					
			(years)	1.005	2	5	10	25	100
Howell Creek	8339	at Rte 9		13.7	29.4	36.7	41.0	46.1	52.8
Unnamed Creek	8325	at Rte 9		7.4	19.7	27.3	32.3	38.7	48.2
				Change (cfs)					
Howell Creek	8339	at Rte 9		8.5	15.0	16.7	17.2	17.3	16.6
Unnamed Creek	8325	at Rte 9		1.8	5.4	6.9	7.6	8.3	8.6
				Change (%)					
Howell Creek	8339	at Rte 9		165%	105%	83%	72%	60%	46%
Unnamed Creek	8325	at Rte 9		32%	37%	34%	31%	27%	22%

Both Howell and Unnamed Creek show a major increase in peak flows. In both cases the increases are due to proposed changes in the drainages that result in more runoff going to each creek than for the existing conditions. For Howell Creek this is because the collector reach (348) channels all of the flow from water courses 5 through 8 to Howell Creek; previously this flow went to the Rte 9 ditch and culvert in front of Fitz Auto and drained directly to Little Bear Creek.

The changes in the Unnamed Creek drainage also increase its peak flows. Unnamed Creek will be routed along the east side of Rte 9 to the confluence with Channels A and B and then will flow through the 73-inch by 55-inch arch CMP under Rte 9 to Little Bear Creek.

Table 5-11 shows the flood frequency values for the Howell Collector Reach (348) which collects off-site runoff from water courses 2 through 8 and the discharge from the Brightwater facility stormwater detention pond (349). It should be noted that the layout for the Brightwater facility is evolving and the values for the stormwater releases from the project site, following detailed design, may slightly vary from those shown in Table 5-11.

Table 5-11 Howell Collector and Brightwater Pond Proposed Conditions Flow Frequency

Drainage	DSN	Location	Return Period	Flow (cfs)					
			(years)	1.005	2	5	10	25	100
Howell Collector Reach	8348	east side of site		12.6	30.6	40.2	46.2	53.6	63.9
Detained Brightwater Discharge	8349	at Rte 9		0.6	0.9	1.2	1.4	1.7	2.2

5.2.2 Flow Duration Results

Flow duration results were plotted using GenScn software. Due to the large number of flow duration plots they are provided in Appendix B.

The Little Bear Creek flow duration plots for reaches 190, 220, and 240 (upstream, adjacent, and downstream, respectively) show no noticeable difference between the existing and proposed conditions plots. The proposed conditions flow duration lines lie directly on top of the existing condition lines. This is because the change in Little Bear Creek streamflow is unnoticeably small.

The flow duration plots for Unnamed Creek and Howell Creek show a large change in streamflow. As described above, these changes are due to additional streams or water courses directed to these two creeks and/or the removal of existing storage ponds.

5.2.3 Mean Monthly Flows

Mean monthly flows were computed for Little Bear Creek at reach 240; Unnamed Creek at Rte 9; Howell Creek at Rte 9. Mean monthly flows are shown in Table 5-12.

Table 5-12 Proposed Conditions Mean Monthly Flow

Drainage	DSN	Location	Flow (cfs)					
			Jan	Feb	Mar	Apr	May	Jun
Little Bear Creek	8240	downstream	31.44	25.93	26.64	19.40	13.89	11.78
Unnamed Creek	8325	at Rte 9	0.79	0.66	0.69	0.52	0.41	0.35
Howell Creek + Water Courses 1 thru 8	8339	at Rte 9	1.22	1.01	1.03	0.76	0.54	0.47

Drainage	DSN	Location	Flow (cfs)					
			Jul	Aug	Sep	Oct	Nov	Dec
Little Bear Creek	8240	downstream	8.51	7.54	7.74	11.20	21.76	27.89
Unnamed Creek	8325	at Rte 9	0.27	0.23	0.24	0.33	0.58	0.71
Howell Creek + Water Courses 1 thru 8	8339	at Rte 9	0.34	0.30	0.30	0.43	0.84	1.08

In comparison to the existing conditions(Table 5-5), Little Bear Creek post-project mean monthly flows decrease every month of the year. The largest decrease occurs in the winter months of November, December, and January. The reason for the decrease in mean monthly flows is the reduction in impervious area from existing conditions to the proposed land use conditions. The difference is 37.64 acres. Based on water balance calculations for the Little Bear Creek Calibration Report (AQUA TERRA Consultants, 2003), this land use change results in a mean annual runoff loss of 41 acre-feet per year (0.37%) in Little Bear Creek stream reach 240 (immediately downstream of the Little Bear-Howell Creek confluence).

Unnamed Creek (which includes the diverted Channels A and B) shows a 20 to 30 percent increase in monthly flows due to an increase in drainage area. This effect is also seen in the low flow analysis below.

The flows in Howell Creek (which includes the diverted watercourses) will more than double..

5.2.4 Low Flow

Low flow was computed in terms of the 10-year, 7-day low flow. The USGS SWSTAT (Surface Water time series Statistics) program, version 4.1, was used to compute 7-day low flows and then calculate the 10-year frequency of occurrence. Although the HSPF model results show 10-year, 7-day low flows of less than 0.1 cfs for many of the smaller stream channels, it should be assumed that these streams run dry during these periods. Table 5-13 shows the 10-year, 7-day low flows for proposed conditions.

Table 5-13 Proposed Conditions 10-Year 7-Day Low Flow

Drainage	DSN	Location	Flow (cfs)
Little Bear Creek	8240	downstream	4.09
Unnamed Creek	8325	at Rte 9	0.119
Howell Creek + Water Courses 1 thru 8	8339	at Rte 9	0.168

Compared to existing conditions (Table 5-6), Little Bear Creek low flows downstream of the Route 9 site increase by a small amount (0.01 cfs, or 0.25 percent). This increase is because of the decrease in impervious area at the site. Impervious area produces only surface runoff and does not contribute to low flows. Its removal increases the opportunity for rainfall to infiltrate into the soil and provide water for low flows.

Unnamed Creek low flows at Route 9 increase by 40 percent due to the change in drainage area resulting from the rerouting of Unnamed Creek on the east side of Route 9 so as to include Channels A and B prior to entering Little Bear Creek. Howell Creek low flows more than double as a result of collecting the flow from water courses 5-8 and sending these flows to Howell Creek rather than directly to Little Bear Creek.

5.2.5 Howell Creek at Route 9

The existing Howell Creek culvert at Route 9 is a 24-inch diameter concrete culvert, according to information obtained from Washington Department of Transportation reports and field observations. This culvert has limited capacity to handle existing flows. This situation could become worse when additional drainage (from water courses 5-8) is directed to Howell Creek as part of the Brightwater facility siting.

Howell Creek at Route 9 existing and proposed conditions flow frequency results are shown in tables 5-2 and 5-10, respectively. They are summarized below in Table 5-14 together with the corresponding flow depths for these flows.

Table 5-14 Howell Creek at Route 9

Drainage	DSN	Location	Return Period (years)	Flow (cfs) 1.005	2	5	10	25	100
Howell Creek (existing)	7339	at Rte 9		5.2	14.4	20.0	23.9	28.8	36.2
Howell Creek (proposed conditions)	8339	At Rte 9		13.7	29.4	36.7	41.0	46.1	52.8
Drainage	**DSN**	**Location**	**Return Period**	**Depth (ft))**					
Howell Creek (existing)	7339	at Rte 9		1.0	2.0	2.7	3.2	4.0	5.6
Howell Creek (proposed conditions)	8339	At Rte 9		2.0	4.1	5.7	6.8	8.0	9.6

Depth is measured from the invert of the upstream side of the Howell Creek culvert under Route 9. Due to the increase in flow and depth at the culvert there may be need to install a larger diameter culvert at this location to handle the expected increase in flow rate and depth.

The HSPF model flow depth results shown in Table 5-14 are approximate and are presented more to show magnitude of depth rather than accuracy of calculation. This is because the depths are computed based on the stage-storage-discharge (FTABLE) information for Howell Creek stream reach 339 and are average reach values. A detailed hydraulic study of the Howell Creek Route 9 culvert is recommended prior to making any decisions regarding the adequate capacity of this culvert.

6 Other Considerations

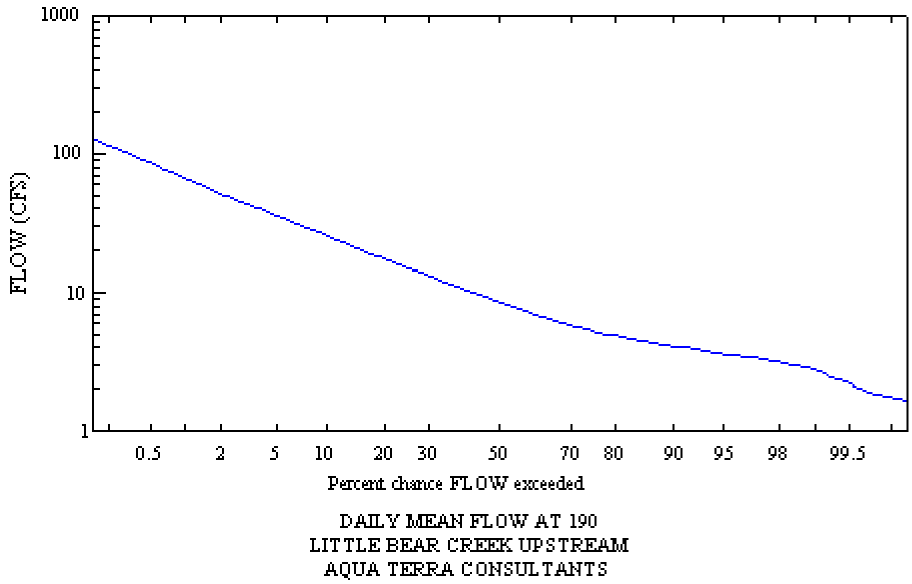
If and when the proposed Site 9 is confirmed for development, it would prove beneficial to either validate the calibrated model and/or expand calibration to included a longer timer period and if possible include on-site measurements proposed to be collected in the Staff Recommended Sampling and Analysis Plan.

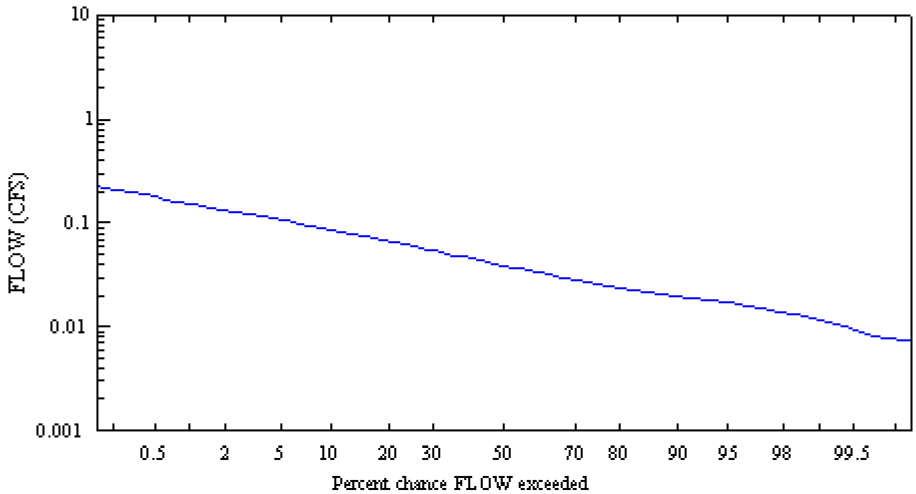
7 References

AQUA TERRA Consultants, 2003. Little Bear Creek Calibration Report (revised draft). King County Watershed Modeling Services. Prepared for King County Water and Land Resources Division, Seattle, WA. June 2003.

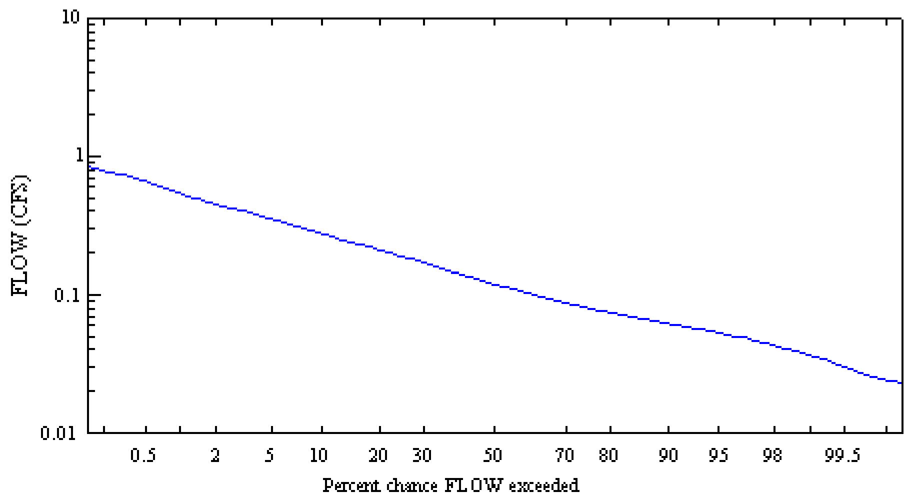
Characterization of Surface and Ground Water at the Proposed Brightwater Route 9 Regional Wastewater Treatment System on Little Bear Creek Sampling and Analysis Plan (DRAFT). King County, Science & Data Management Section, Seattle, WA. April 2003

Appendix A. Flow Duration Plots: Existing Conditions

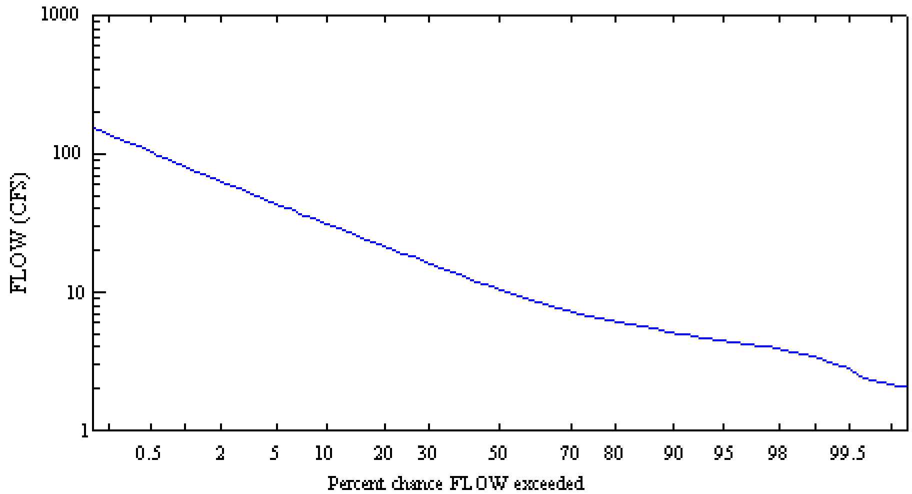




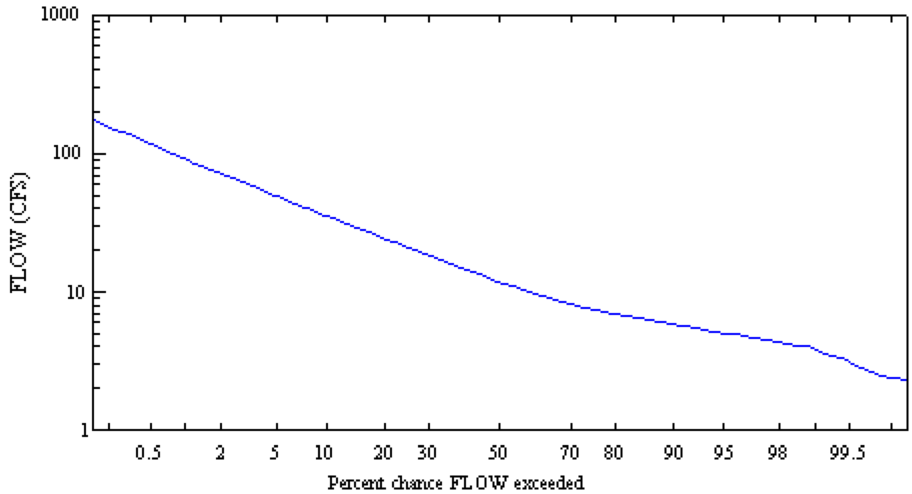
DAILY MEAN FLOW AT 319
RTE 9 DITCH N OF UNNAMED CREEK
AQUA TERRA CONSULTANTS



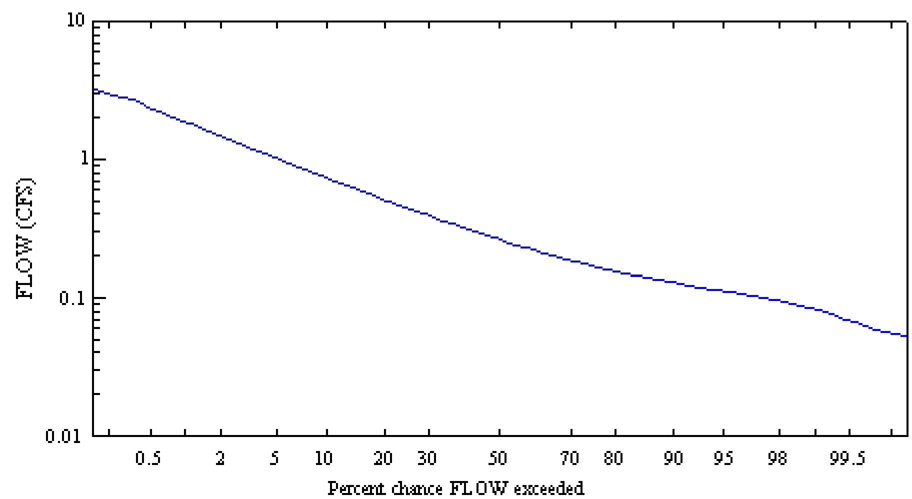
DAILY MEAN FLOW AT 321
UNNAMED CREEK AT RTE 9
AQUA TERRA CONSULTANTS



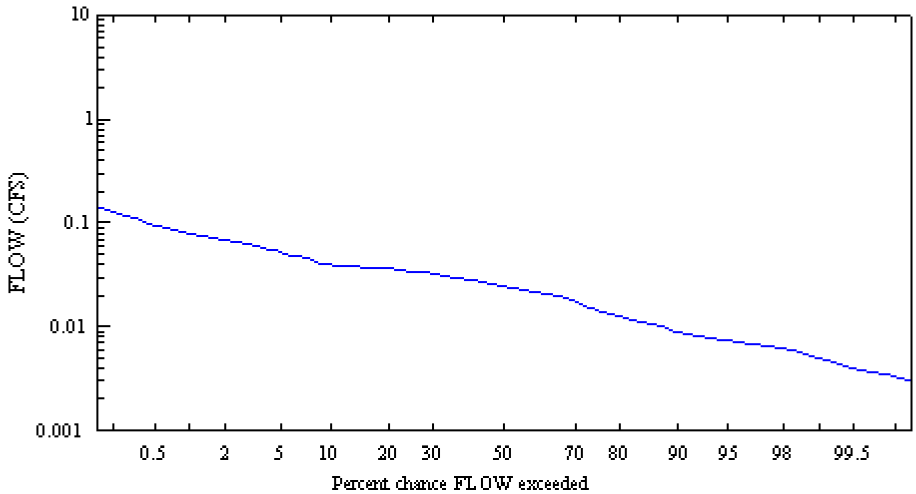
DAILY MEAN FLOW AT 220
LITTLE BEAR CREEK ADJACENT
AQUA TERRA CONSULTANTS



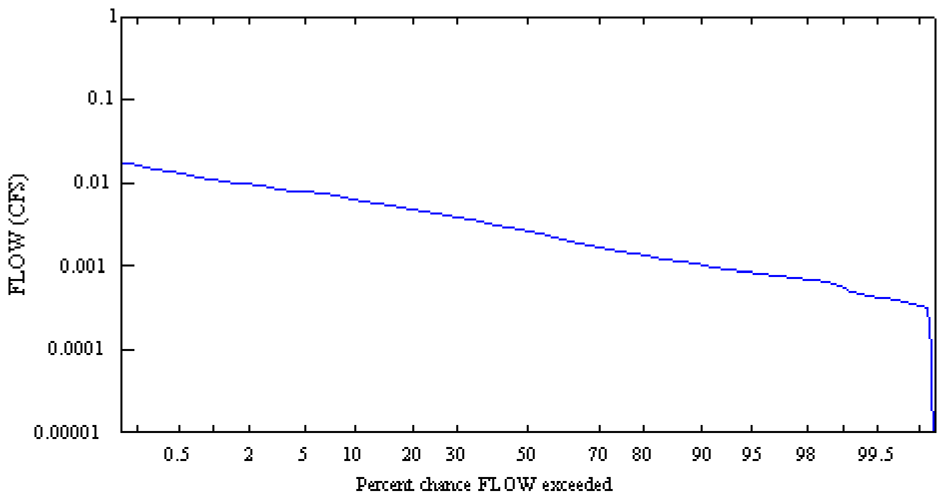
DAILY MEAN FLOW AT 240
LITTLE BEAR CREEK DOWNSTREAM
AQUA TERRA CONSULTANTS



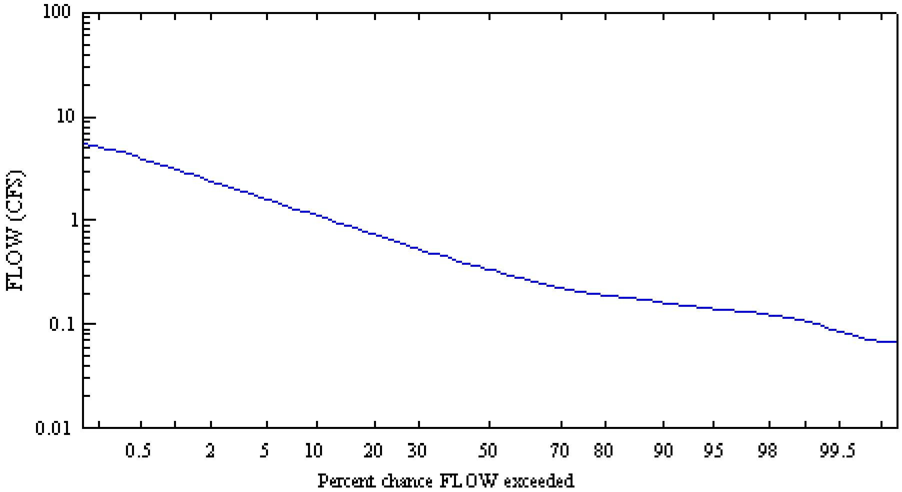
DAILY MEAN FLOW AT 325
CHANNEL A AND B AT RTE 9
AQUA TERRA CONSULTANTS



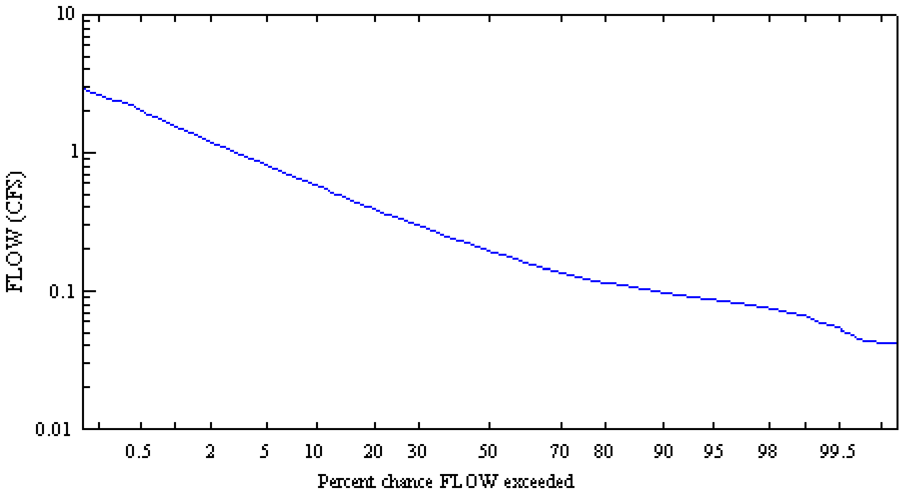
DAILY MEAN FLOW AT 327
WOODINVILLE BUSINESS PARK NORTH AT RTE 9
AQUA TERRA CONSULTANTS



DAILY MEAN FLOW AT 328
WOODINVILLE BUSINESS PARK SOUTH AT RTE 9
AQUA TERRA CONSULTANTS

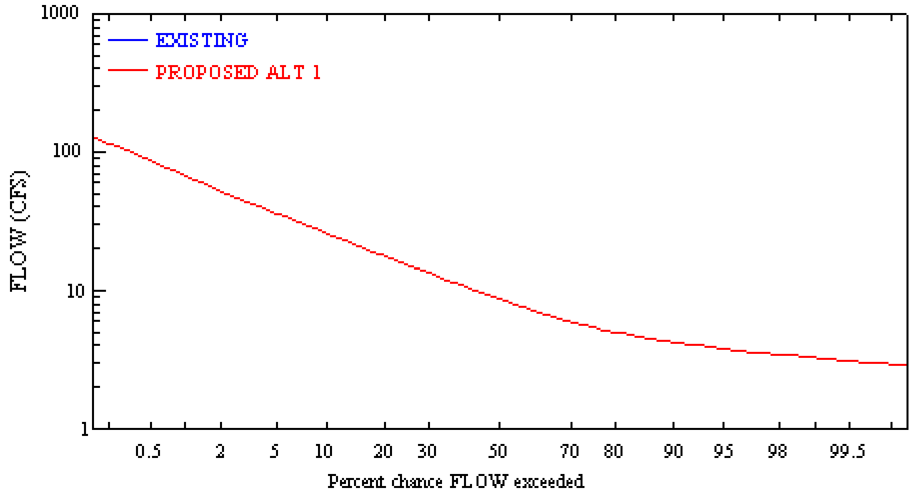


DAILY MEAN FLOW AT 338
RTE 9 DITCH IN FRONT OF FITZ AUTO
AQUA TERRA CONSULTANTS

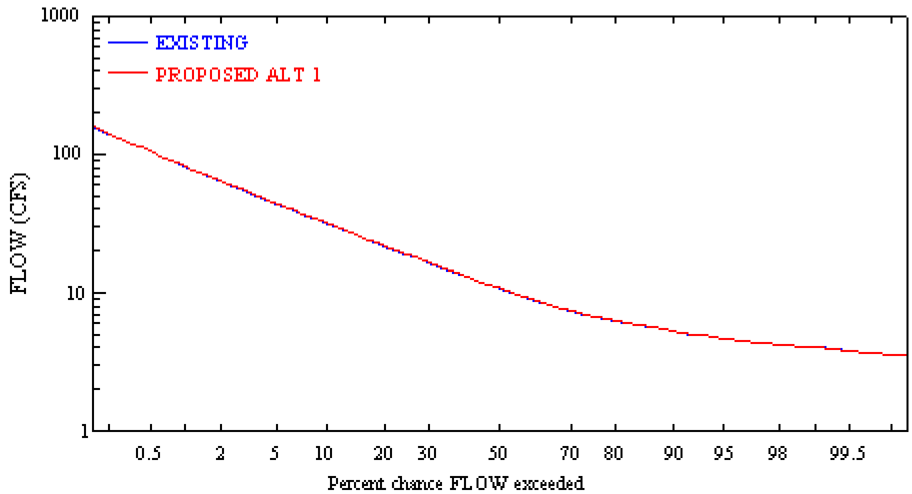


DAILY MEAN FLOW AT 339
HOWELL CREEK AT RTE 9
AQUA TERRA CONSULTANTS

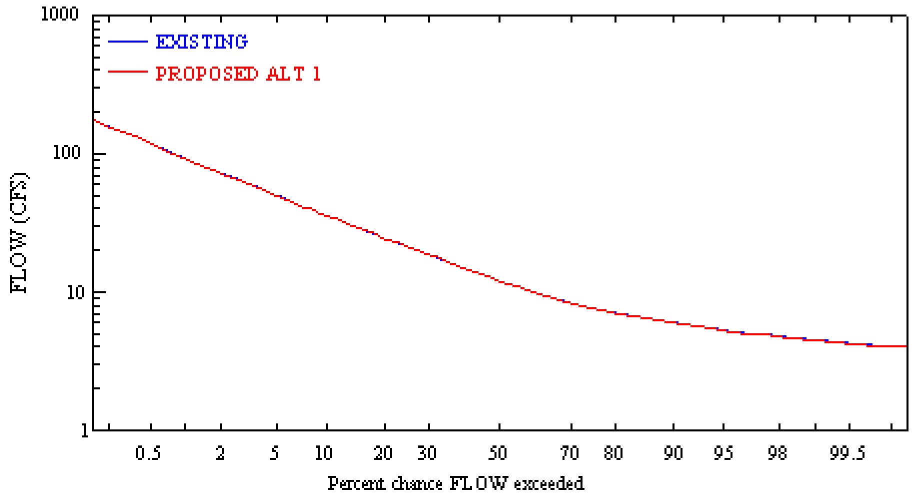
Appendix B. Flow Duration Plots: Proposed Conditions



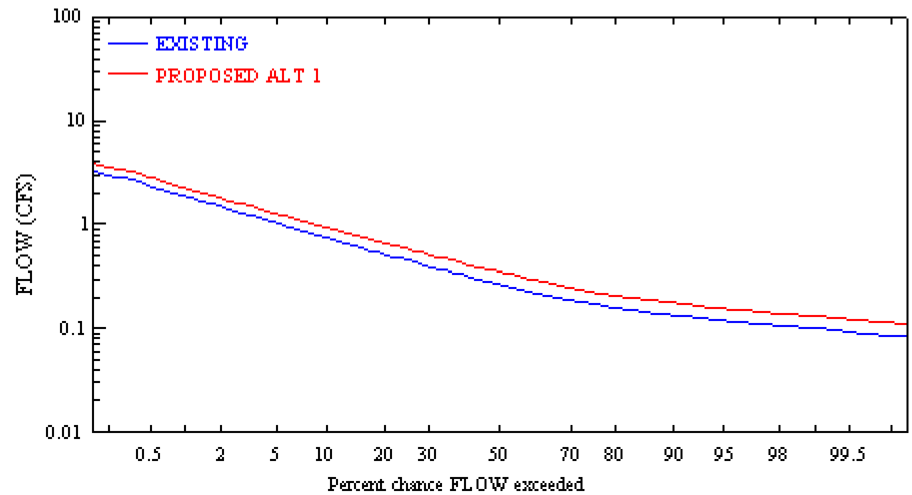
Analysis Plot for DAILY MEAN FLOW AT 190
LITTLE BEAR CREEK UPSTREAM
AQUA TERRA CONSULTANTS



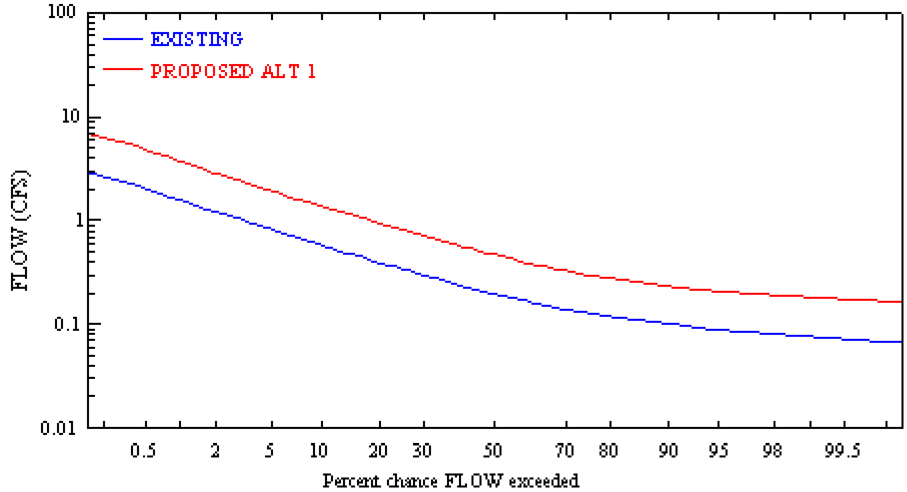
Analysis Plot for DAILY MEAN FLOW AT 220
LITTLE BEAR CREEK ADJACENT
AQUA TERRA CONSULTANTS



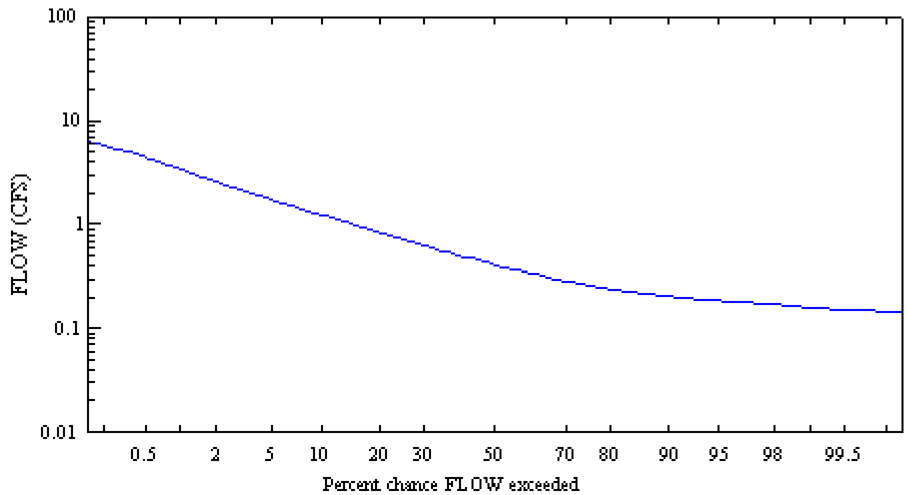
Analysis Plot for DAILY MEAN FLOW AT 240
LITTLE BEAR CREEK DOWNSTREAM
AQUA TERRA CONSULTANTS



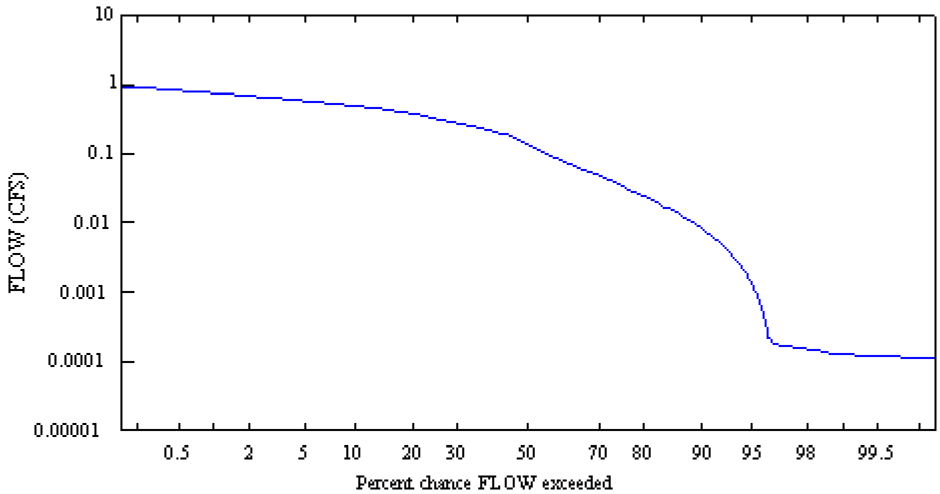
DAILY MEAN FLOW AT 325
UNNAMED CREEK AT RTE 9
AQUA TERRA CONSULTANTS



DAILY MEAN FLOW AT 339
HOWELL CREEK AT RTE 9
AQUA TERRA CONSULTANTS



DAILY MEAN FLOW AT 338
PROPOSED ALT 1 COLLECTOR REACH (WATER COURSES 2-8)
AQUA TERRA CONSULTANTS



DAILY MEAN FLOW AT 349
PROPOSED ALT 1 DETAINED BRIGHTWATER SITE RUNOFF
AQUA TERRA CONSULTANTS

ATTACHMENT B

Grain Size Distribution of Sediment Samples Collected from Little Bear Creek

ATTACHMENT B
Grain Size Distribution of Sediment Samples Collected from Little Bear Creek

Brightwater Project
Little Bear Creek
Grain size distribution
June 10, 2003.

Sample #

Sample 1	Sieve (in)	grams	Cum. gm	% retained	% passing
	3	0			
	1.5	589.8	589.8	12.2	87.8
	1.25	418.8	1008.6	20.8	79.2
	1	544.6	1553.2	32.0	68.0
	0.75	864.9	2418.1	49.8	50.2
	0.5	588.9	3007	62.0	38.0
	0.375	417	3424	70.6	29.4
	0.25	382.2	3806.2	78.4	21.6
	#4	189.3	3995.5	82.3	17.7
	#8	269.5	4265	87.9	12.1
	#10	37	4302	88.7	11.3
	#20	173.5	4475.5	92.2	7.8
	< #20	376.9	4852.4	100.0	0.0
	Total Wt.	4852.4			
	Original Wt.				

Sample 2	Sieve (in)	grams	Cum. gm	% retained	% passing
	3	0			
	1.5	2108.8	2108.8	42.9	57.1
	1.25	774.6	2883.4	58.7	41.3
	1	898.5	3781.9	77.0	23.0
	0.75	515.1	4297	87.5	12.5
	0.5	385	4682	95.3	4.7
	0.375	102.9	4784.9	97.4	2.6
	0.25	61.4	4846.3	98.6	1.4
	#4	21.5	4867.8	99.1	0.9
	#8	19.3	4887.1	99.5	0.5
	#10	3.4	4890.5	99.5	0.5
	#20	12.2	4902.7	99.8	0.2
	< #20	10.8	4913.5	100.0	0.0
	Total Wt.	4913.5			
	Original Wt.				

Sample 4	Sieve (in)	grams	Cum. gm	% retained	% passing
	3	0	0	0.0	100.0
	1.5	1362.6	1362.6	32.7	67.3
	1.25	841	2203.6	53.0	47.0
	1	483.4	2687	64.6	35.4
	0.75	425.8	3112.8	74.8	25.2
	0.5	575.9	3688.7	88.6	11.4
	0.375	184.6	3873.3	93.1	6.9
	0.25	112.5	3985.8	95.8	4.2
	#4	51.7	4037.5	97.0	3.0
	#8	64.6	4102.1	98.6	1.4
	#10	7.7	4109.8	98.8	1.2
	#20	27	4136.8	99.4	0.6
	< #20	24.3	4161.1	100.0	0.0
	Total Wt.	4161.1			
	Original Wt.				

Sample 5	Sieve (in)	grams	Cum. gm	% retained	% passing
	3	0			
	1.5	164.8	164.8	4.6	95.4
	1.25	298.7	463.5	12.9	87.1
	1	362.2	825.7	23.1	76.9
	0.75	591.6	1417.3	39.6	60.4
	0.5	569.2	1986.5	55.5	44.5
	0.375	282	2268.5	63.3	36.7
	0.25	223.2	2491.7	69.6	30.4
	#4	131.7	2623.4	73.2	26.8
	#8	178.6	2802	78.2	21.8
	#10	25.6	2827.6	79.0	21.0
	#20	226.6	3054.2	85.3	14.7
	< #20	527.3	3581.5	100.0	0.0
	Total Wt.	3581.5			
	Original Wt.				

ATTACHMENT C

Methods for Calculating Incipient Motion of Sediment

ATTACHMENT C

Methods for Calculating Incipient Motion of Sediment

Yang's Method

Yang's criteria (1996) relate analytical forces on a spherical sediment particle at the bottom of an open channel. When the Reynolds number is greater than 70, a linear relationship between the average critical velocity at incipient motion and a particle's fall velocity is assumed:

$$Vc = 2.05 \times w$$

where Vc= critical velocity at incipient motion (ft/s)
w= fall velocity (ft/s)

For particle sizes greater than 2 mm in 16 degree C water, w can be approximated by:

$$w = 6.01 \times Dmean^{1/2}$$

where Dmean= particle size below which 50% are finer (ft)

Meyer-Peter and Mueller Method

Sediment size at incipient motion can be obtained from:

$$Dmean = (S \times Dp) / (K \times (n/(D90^{1/6}))^{3/2})$$

where Dmean= particle size below which 50% are finer (mm)
S= channel slope
Dp= mean flow depth (ft)
K= 0.19 (constant when depth is in ft)
n= Manning's roughness coefficient (0.04)
D90= particle size below which 90% are finer (mm)

Rearranging this equation provides a method for estimating the mean flow depth (Dp) that would be required to initiate motion of the armor layer.